

# **A LN<sub>2</sub>-COOLED ELECTROSTATIC RING**

**A progress report since COOL-03 (POSTER presentation)**

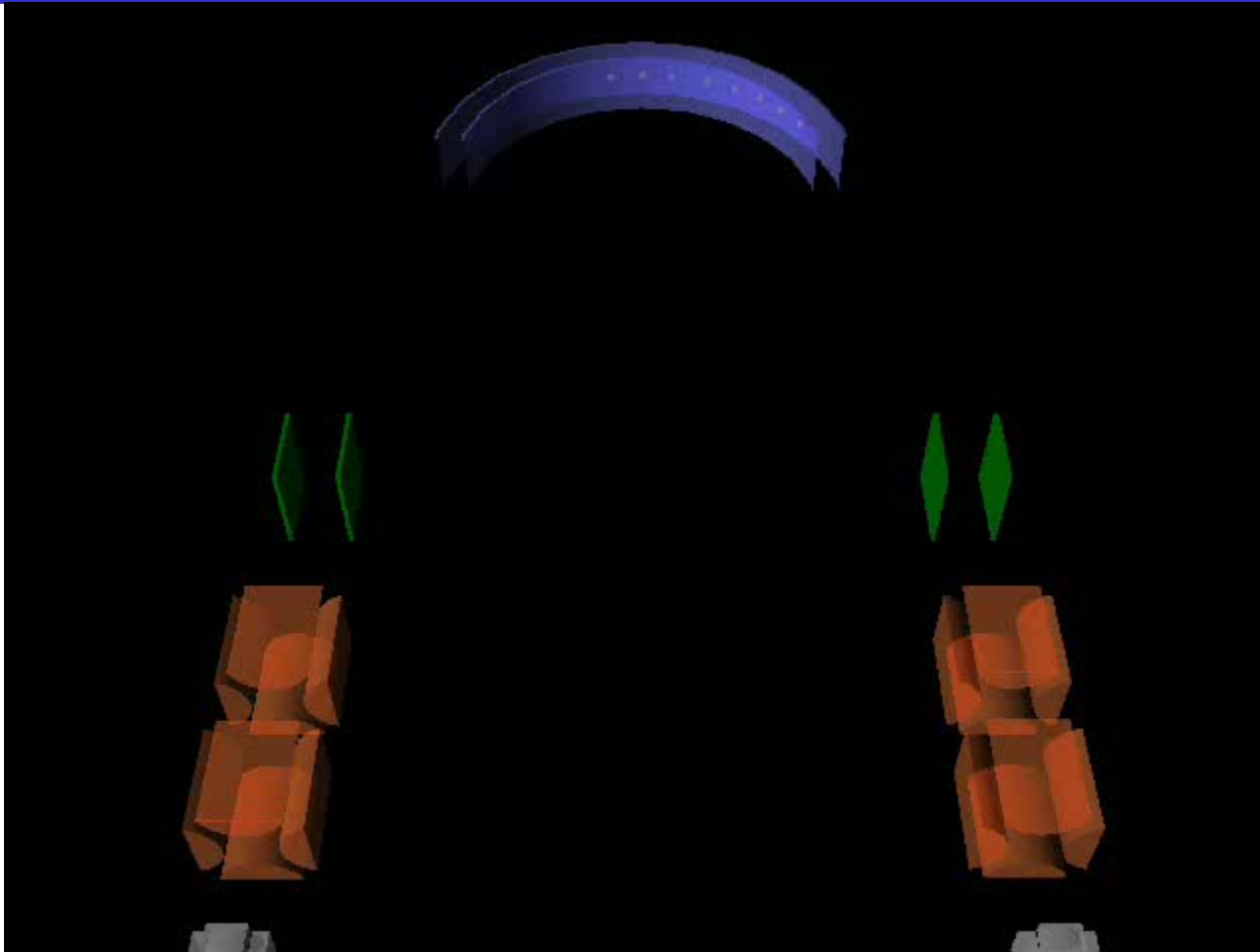
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# What we have stored in TMU E-ring

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**He<sup>+</sup>, Ne<sup>+</sup>, Ar<sup>+</sup>, Kr<sup>+</sup>, Xe<sup>+</sup>**

**CO<sup>+</sup>, CO<sub>2</sub><sup>+</sup>, CO<sup>2+</sup>, CO<sub>2</sub><sup>2+</sup>**

**C<sub>60</sub><sup>+</sup>, C<sub>70</sub><sup>+</sup>, C<sub>84</sub><sup>+</sup>, C<sub>60</sub><sup>-</sup>, C<sub>70</sub><sup>-</sup>, porphyrin<sup>-</sup>**

# Outline

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- Ion storage for more than 1 min.
- Ion storage at **LN<sub>2</sub> temperature**
- **Magnet-free ion injection** system in combination of pulsed-HV and Laser desorption ion source.
- **Simultaneous storage of several kinds of ions**, and selection of a specific ion by bunching technique
- We started **spectroscopy** of cluster/molecular ions by introducing tunable visible **OPO-LASER**
  - metastable molecular ion
  - cluster/biomolecular ions

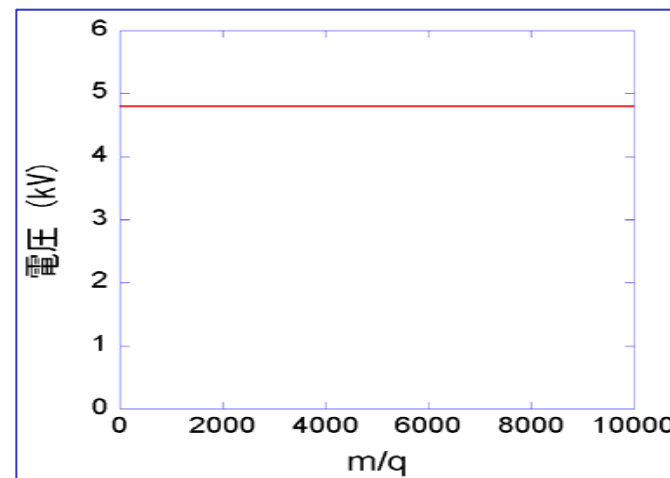
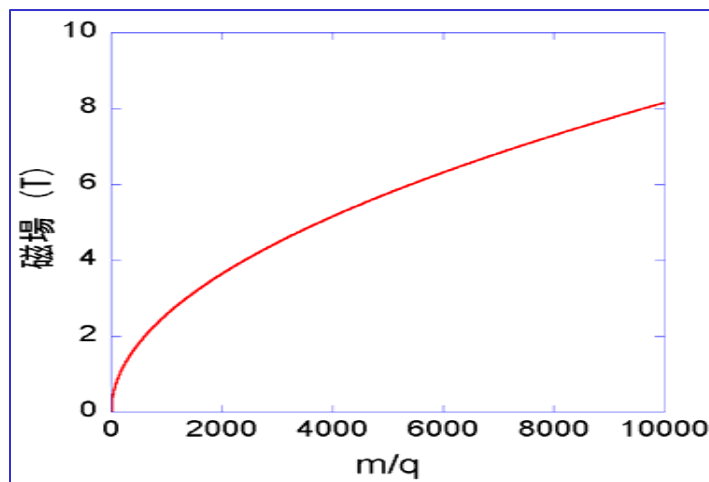
# Characteristics of E (electrostatic) -Ring

- storage of very heavy ions

Magnetic control

Electric control

For bending 20kV(=V<sub>0</sub>) ions at the radial curvature of r<sub>0</sub> = 25cm



30 keV C<sub>60</sub><sup>+</sup> :

2.7 T

30 keV C<sub>60</sub><sup>+</sup> :

distance between electrodes:  
30 mm, voltage 7.2 kV

$$B \propto \sqrt{m\varepsilon / q}$$

$$E \propto \varepsilon / q$$

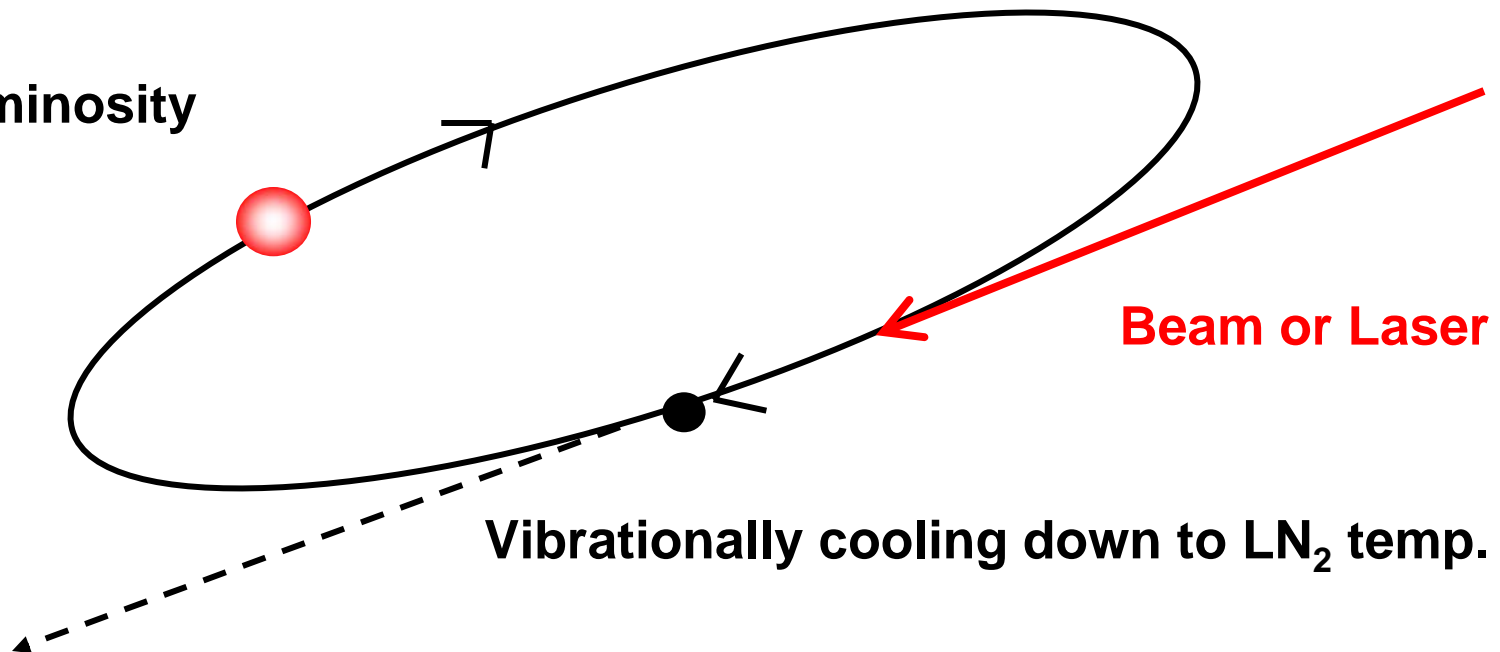
ion mass *m* and charge *q* dependence

# Characteristics of E (electrostatic) -Ring

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No mass restriction of stored ions

High Luminosity

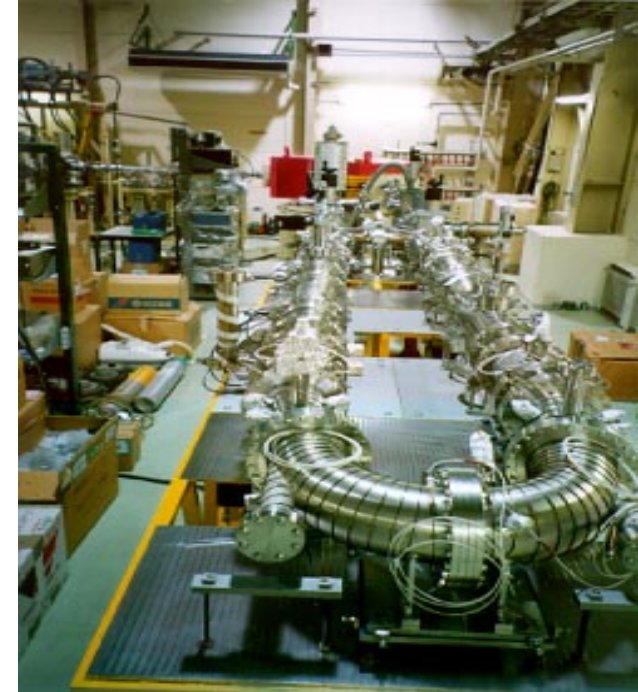


Detection of neutral product

suitable for atomic physics, chemistry, solid state physics  
of huge molecular ions (cluster, biomolecule, nano-particle )

# Electrostatic Ion Storage Rings

**FIRST (ELISA, Aarhus(DEN))**



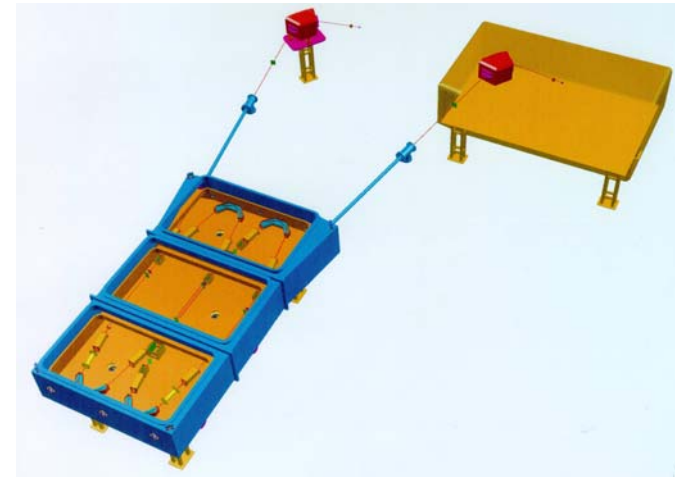
**SECOND (KEK Tanabe)**



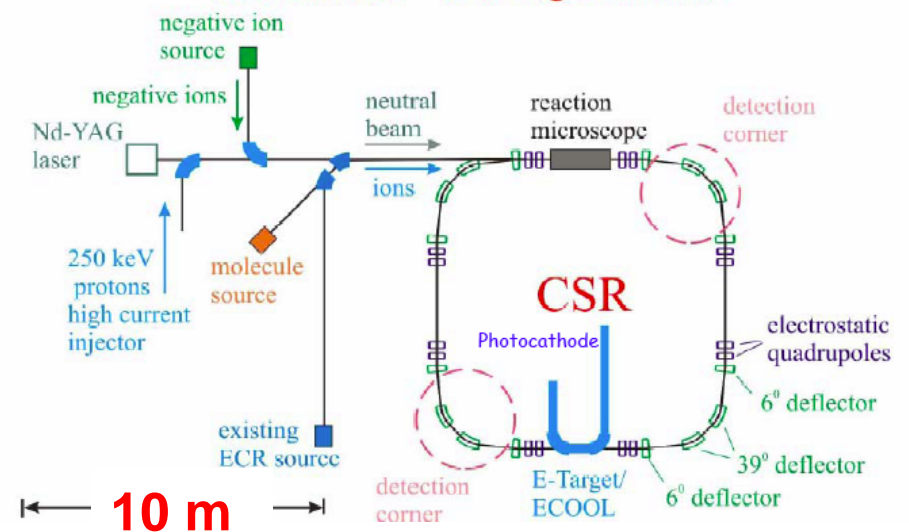
**THIRD (TMU )**

# E-ring under construction

- **Manne Siegbahn Institute**  
(Stockholm, Sweden)  
LHe temp. Double ring:
- **Max Planck Institute**  
(Heidelberg, Germany)  
LHe temp.  
Hugh complex of various  
ion sources etc..



CSR with 39° bending elements



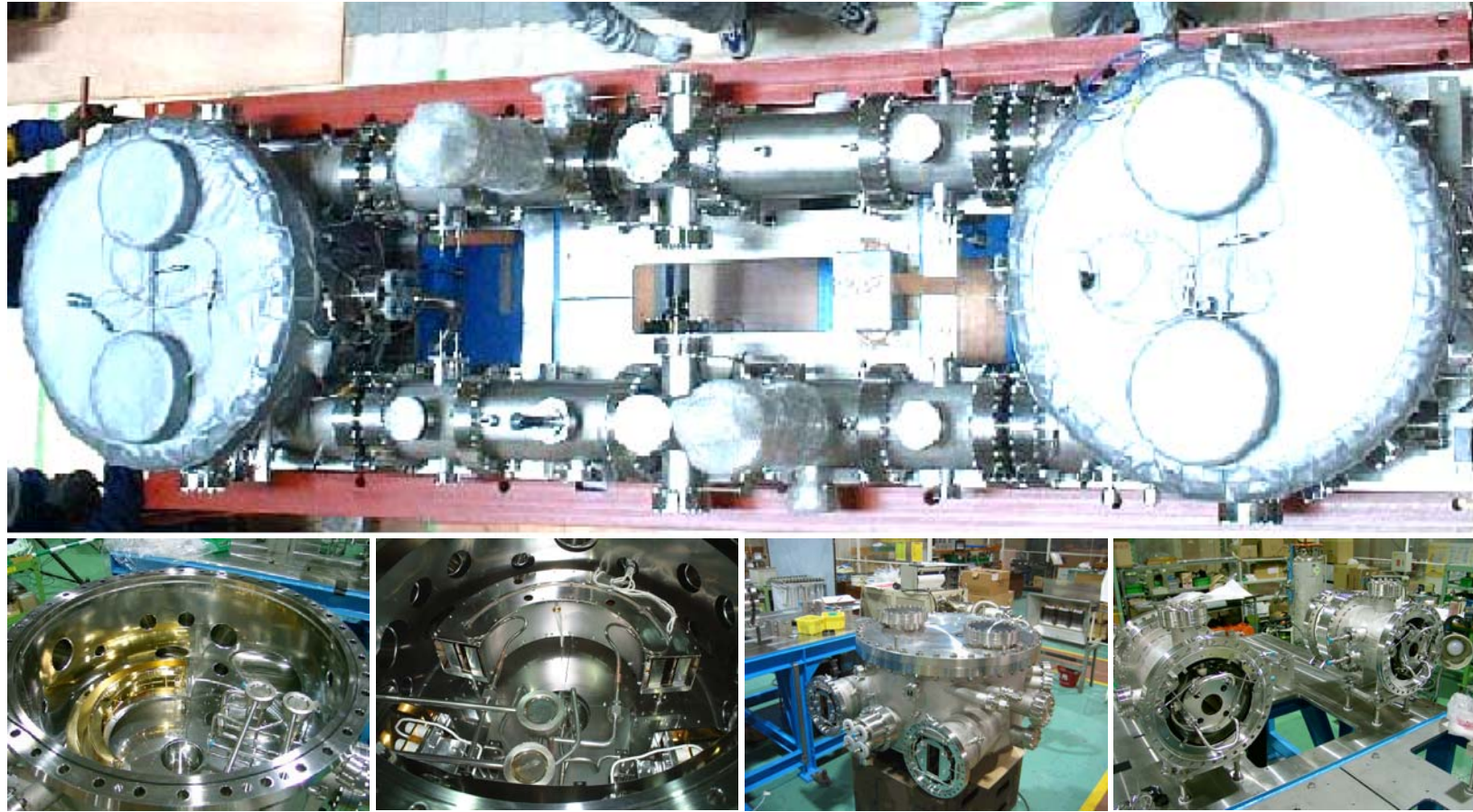


# TMU E-Ring under Construction at Toshiba



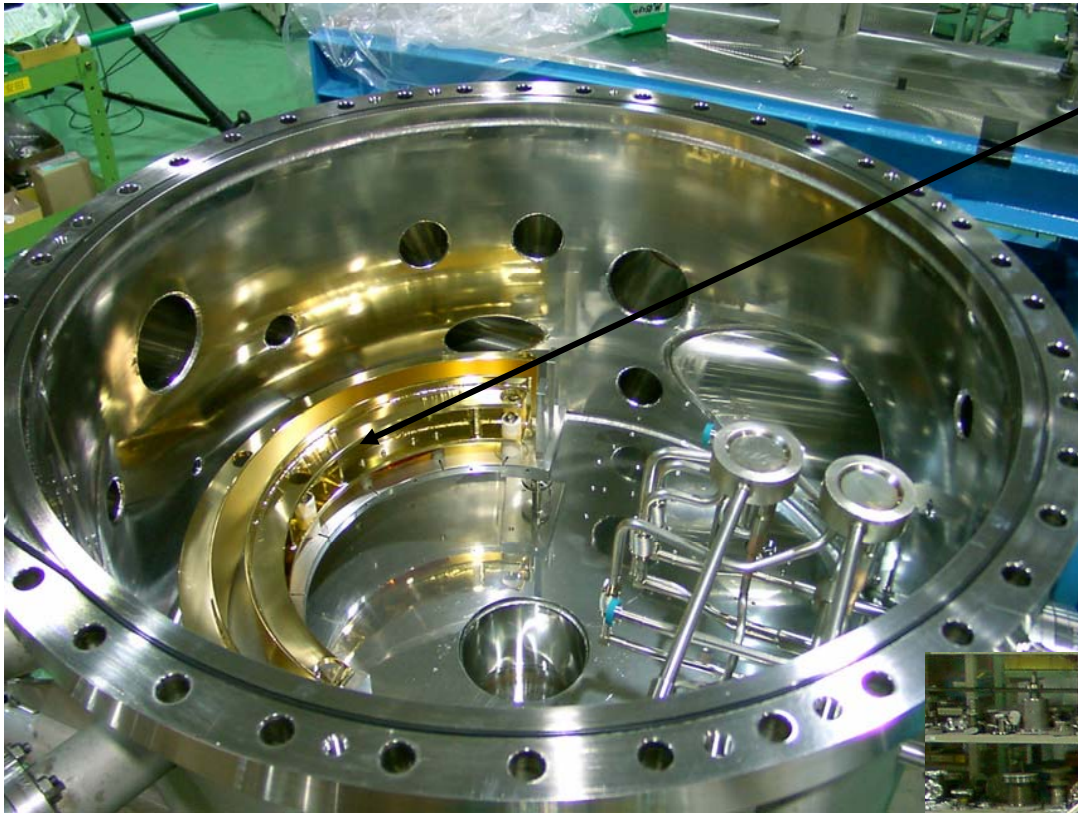


# TMU E-Ring



- total length : 7.7 m  
( 30 keV H<sup>+</sup> period : **3.2 μs** )
- vacuum 10<sup>-9</sup> Pa order

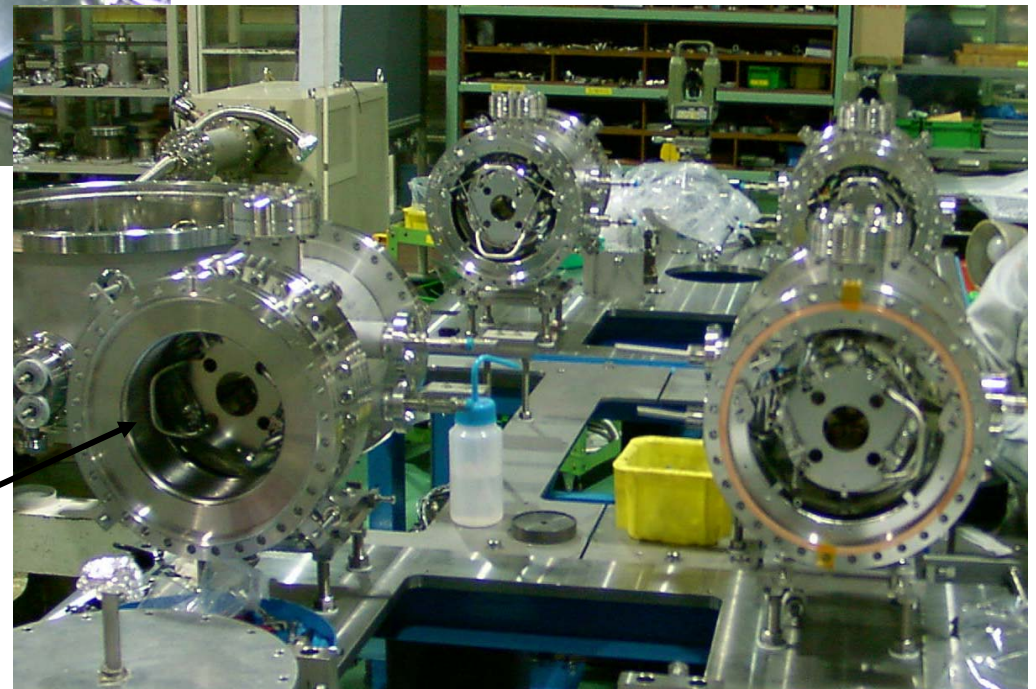




160° deflector

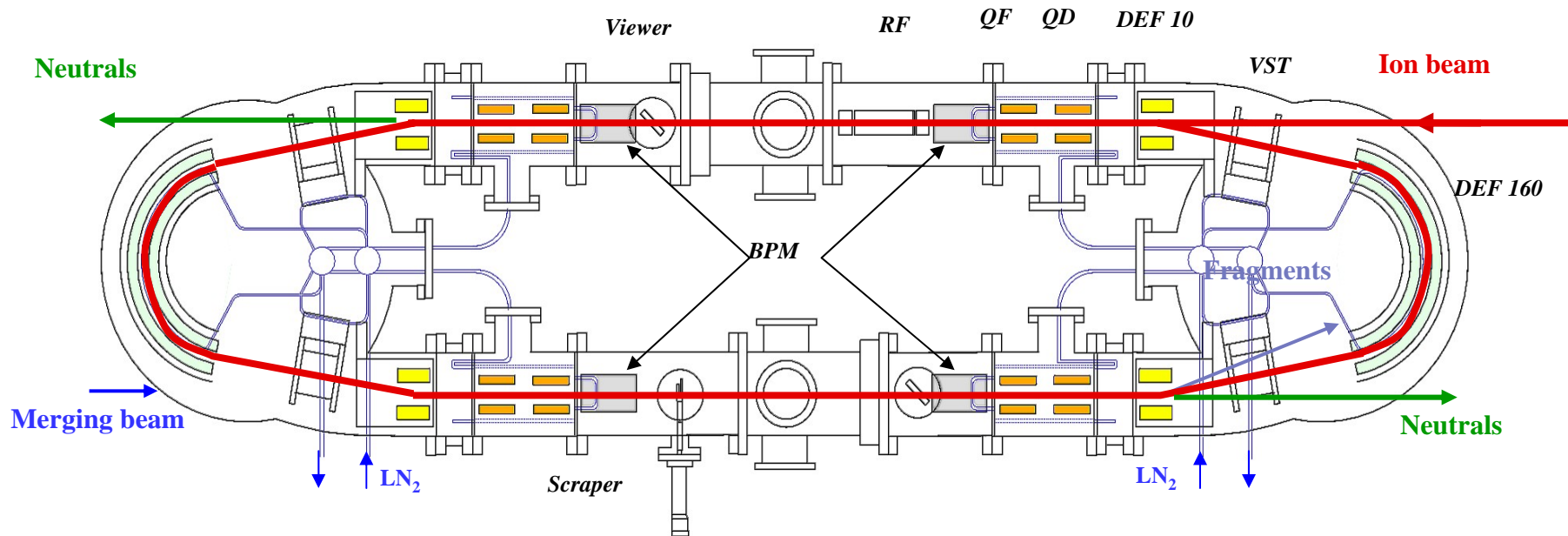
electrode: Au plated

design/manufacturing/assembly  
taking **heat shrinking** into account  
(0.5 mm precision)



quadrupole

# TMU E-Ring



- total length : 7.7 m  
( **30 keV** H<sup>+</sup> period : **3.2 μs** )
- vacuum 10<sup>-9</sup> Pa order

- trajectory control
 

160°deflector(DEF160)	×2
10°deflector(DEF10)	×4
Quadrupole (QD,QF)	×4
Deflector (VST)	×4

similar lattice structure to  
ELISA, and KEK-ring

Totally 52 electrodes

# Characteristics of TMU E-Ring

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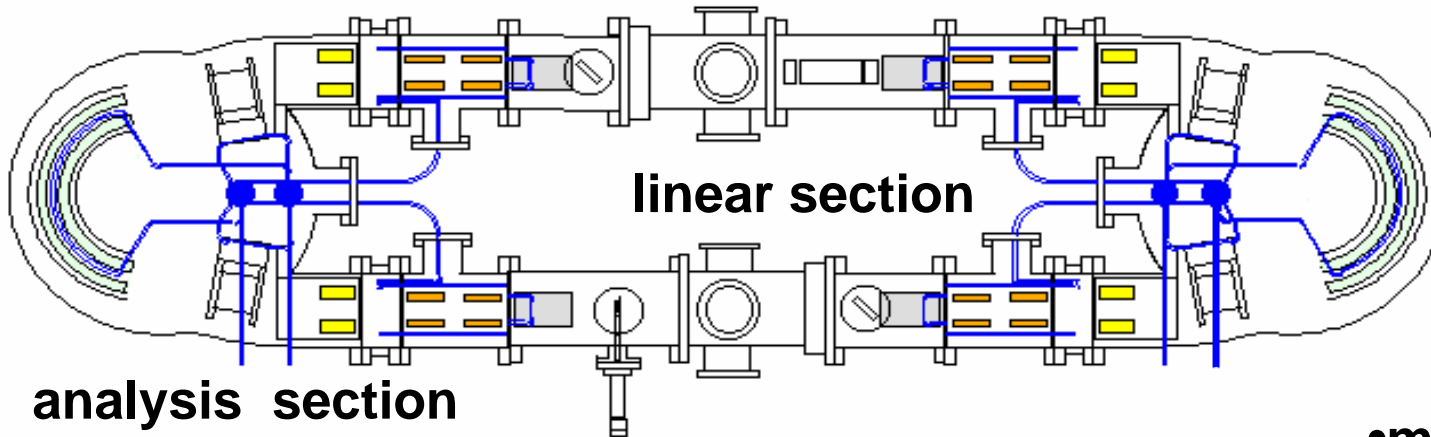
- **regular operation at 80 K**
- **magnet-free ion injection system**
  - 1) TOF-mass selection of pulsed beam at the injection region
  - 2) FT-mass selection of all ions after injection to the ring
- **enough space**  
at the bending region to insert the detection system of product ions  
(mass/charge changed)

(2 round chamber of diameter in 80cm , height 40cm)



# Baking

UHV is critical



•mantle heater 6 kW×2

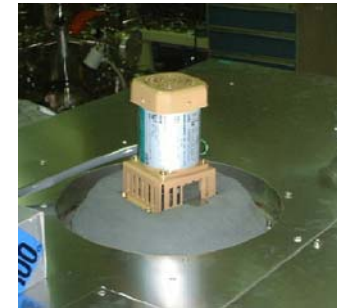
fin-heater 5 kW



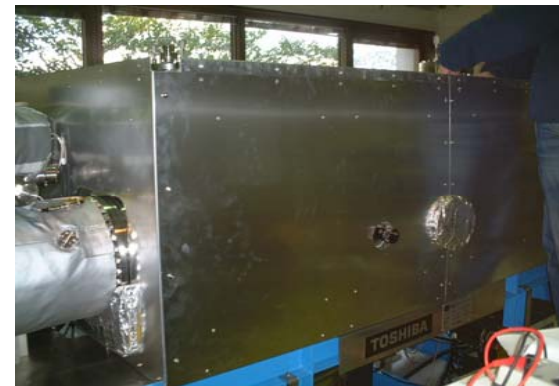
Temp. monitoring

- mantle heater
- fin heater
- linear section

covering  
by heat-insulation  
material

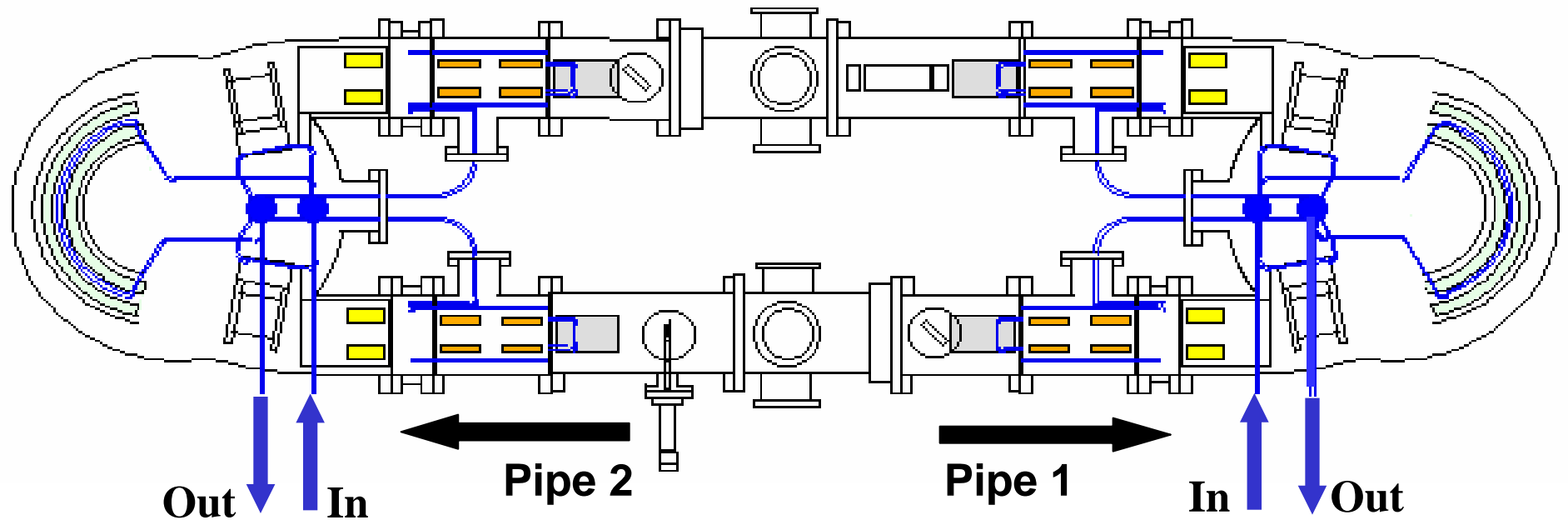


temp. averaging  
by fan





# Cooling Cooling of electrodes by circulated LN<sub>2</sub> in the ring



Cooling of low-temp. shield and electrodes  
by circulation of LN<sub>2</sub> through pipes 1,2

(CF. Whole ring in a pool of LN<sub>2</sub> at Aarfus)

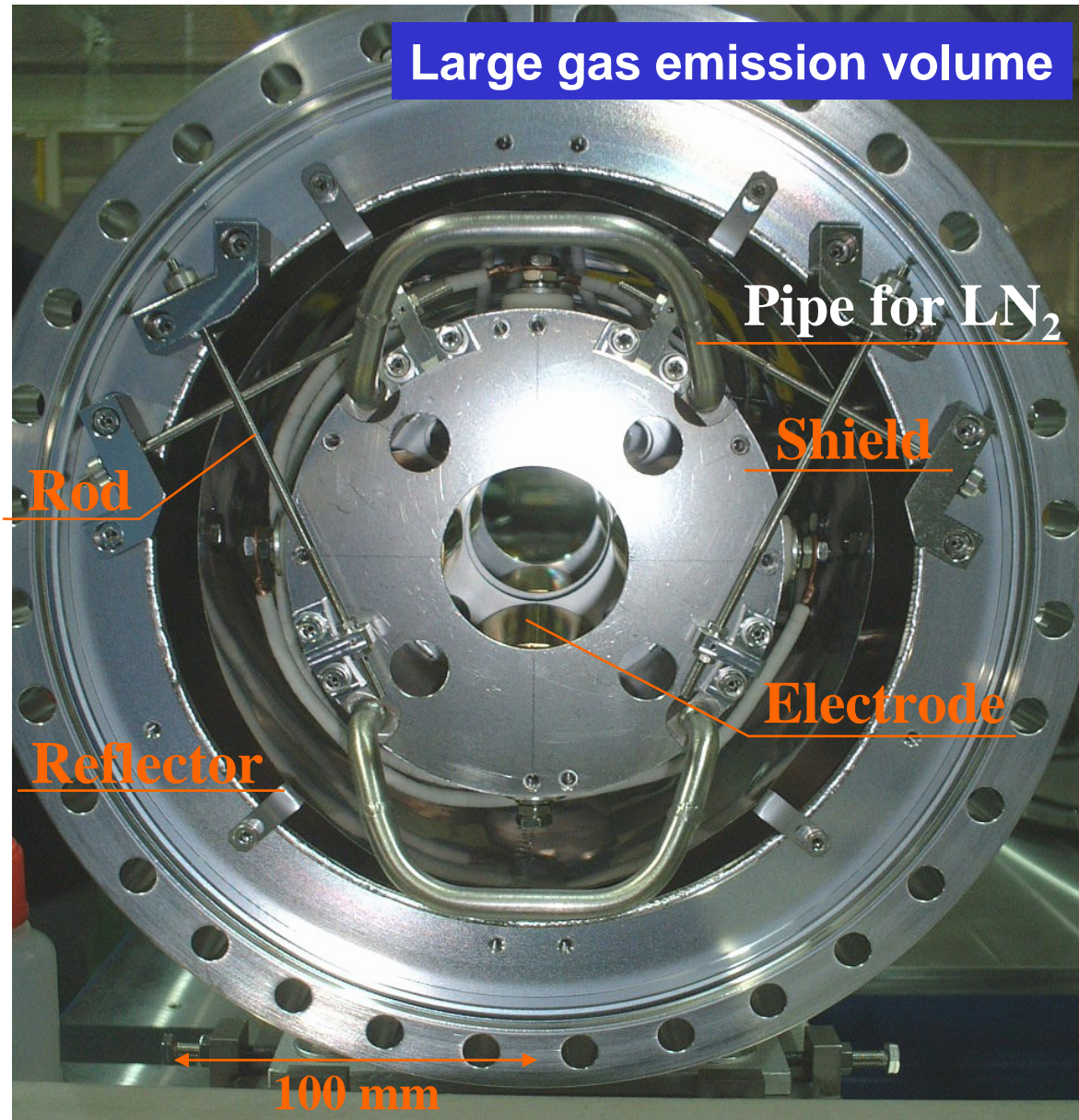
in the ring: radiation >> conduction

automatic production and circulation system of LN<sub>2</sub>



## Three-folded Structure for Heat-Insulation

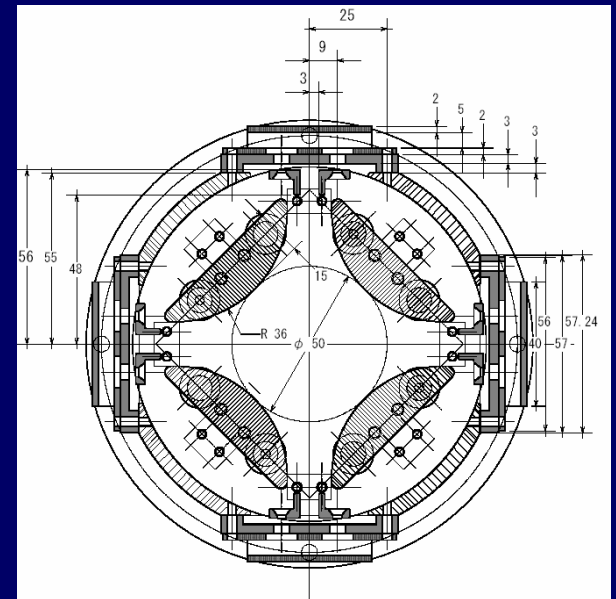
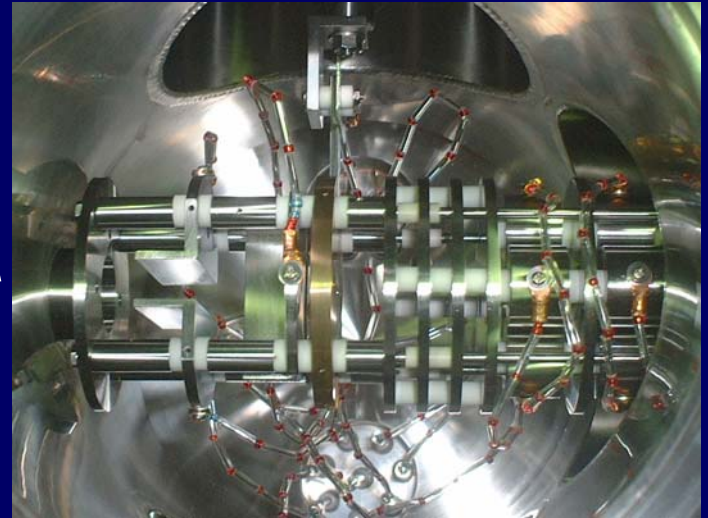
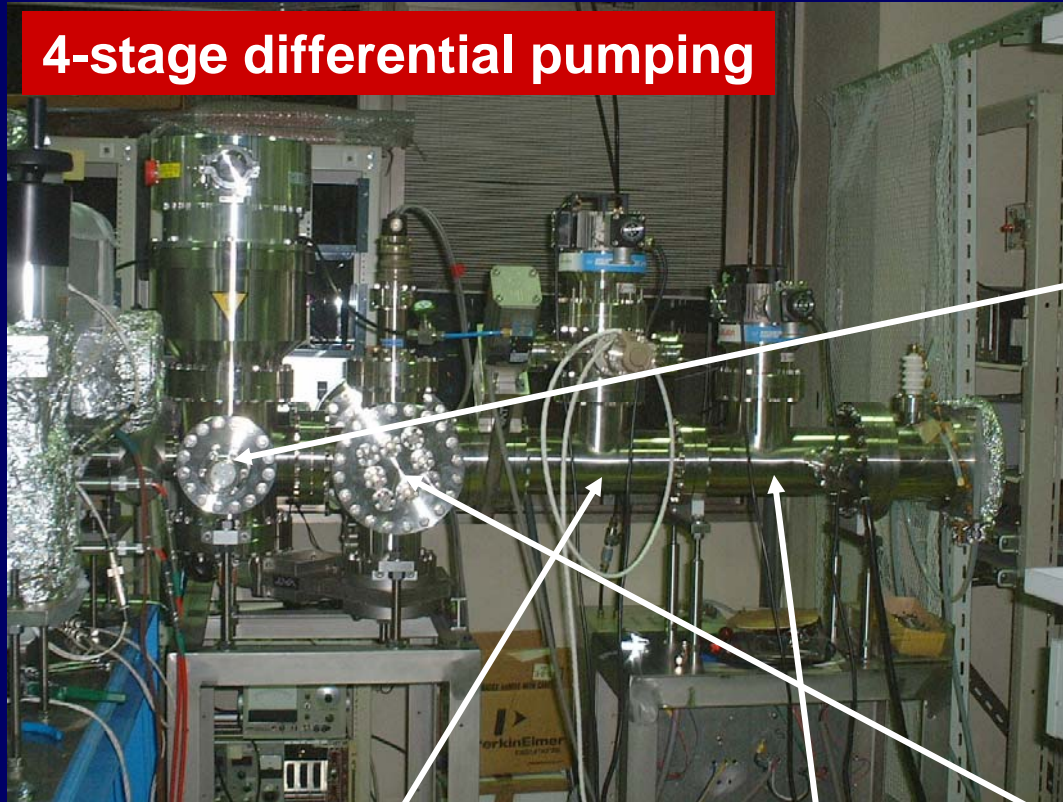
- LN<sub>2</sub> cooling of low temp. shielding
- connection of low temp. shield and electrodes by insulator
- sustention of low temp. shielding by titanium-alloy rod with high insulation
- reflector for preventing from radiation between low temp. shielding and vacuum wall
- design/manufac./assembly considering heat shrink (0.5mm precision)
- surrounding of 80% of beam trajectory by LN<sub>2</sub>





# Ion Injection System

4-stage differential pumping

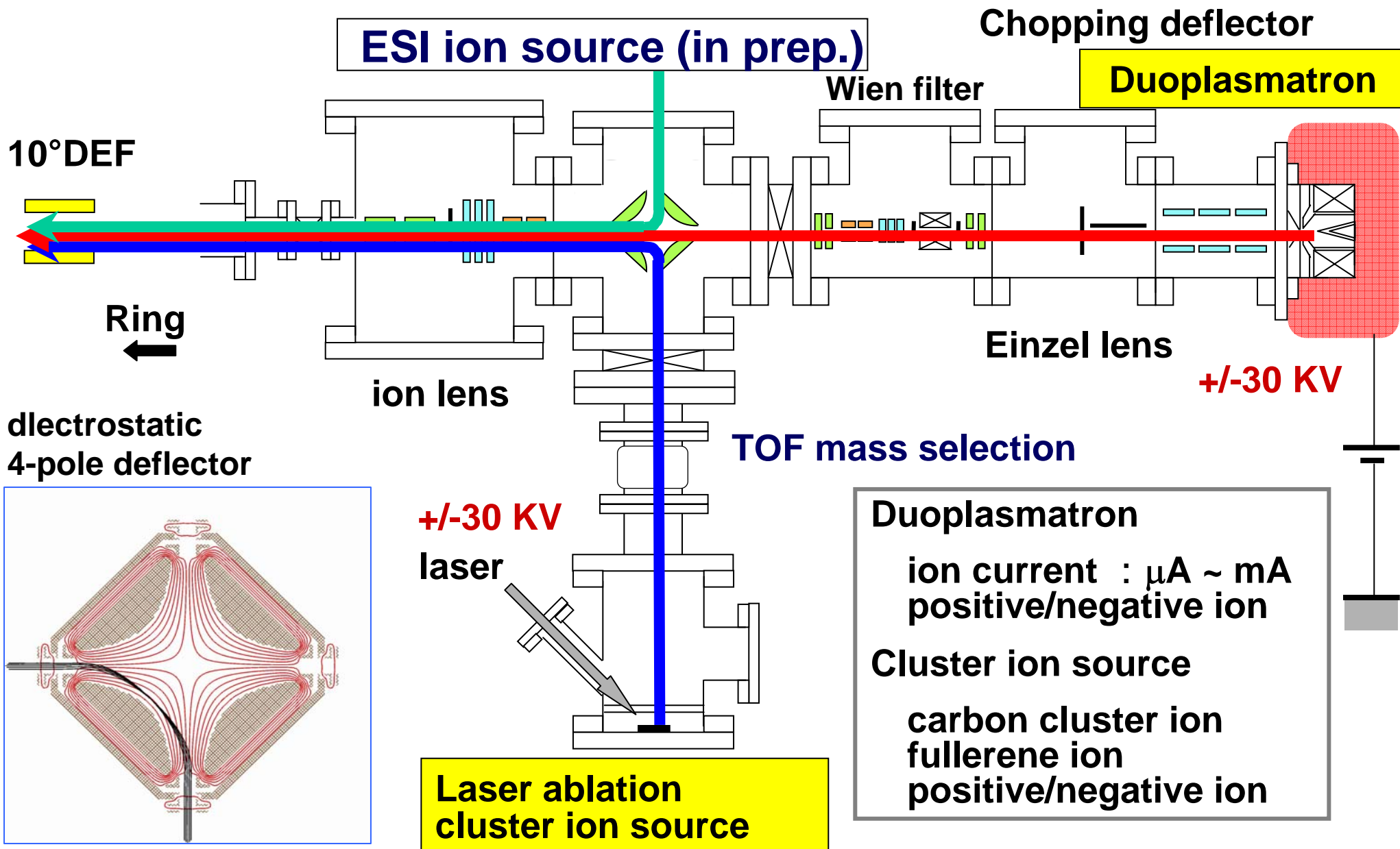


Chopping deflector  
for pulsed beam extraction

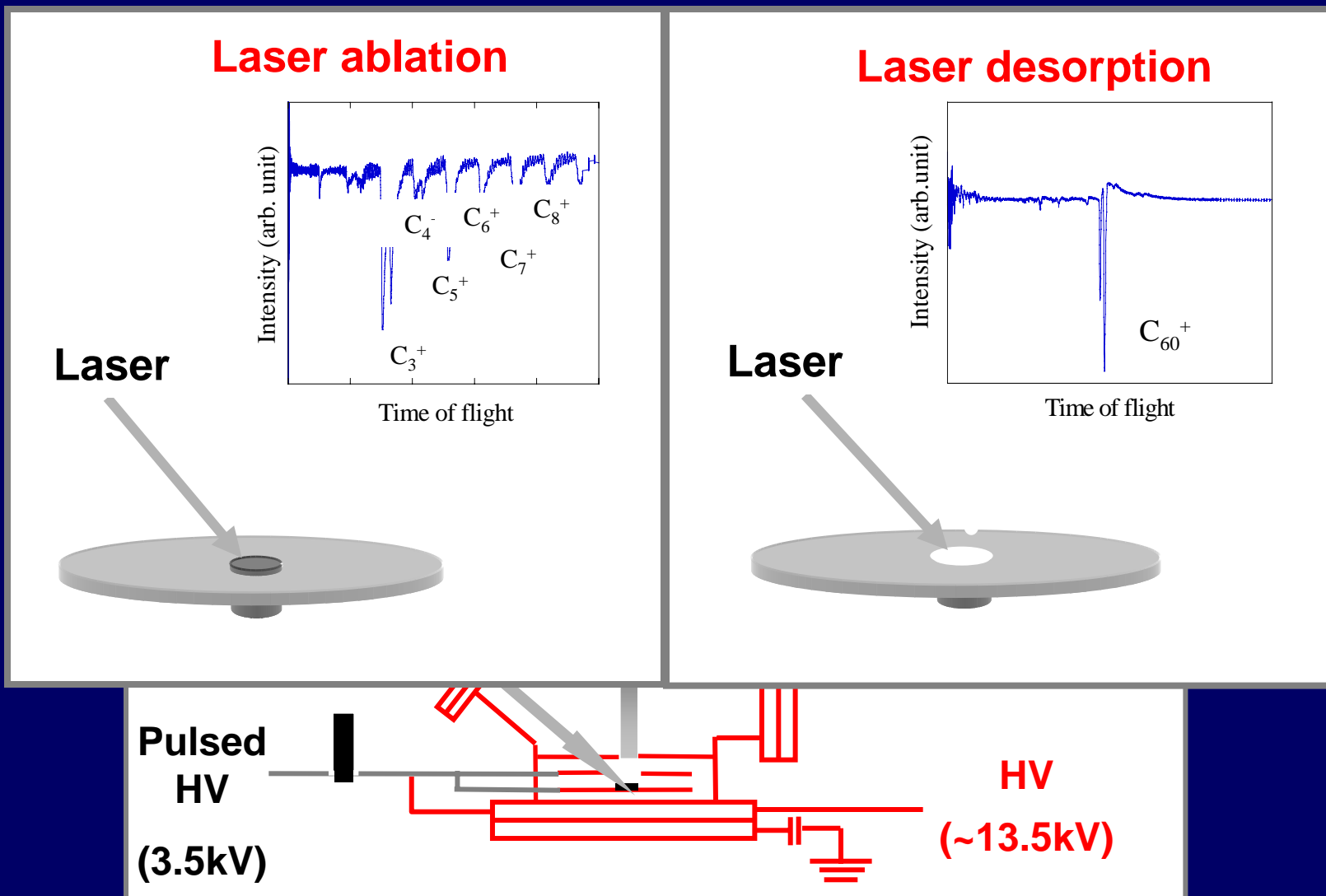
$E \times B$  ion selection

1m

# Ion Sources and Ion Injection System



# Carbon Cluster Ion Source



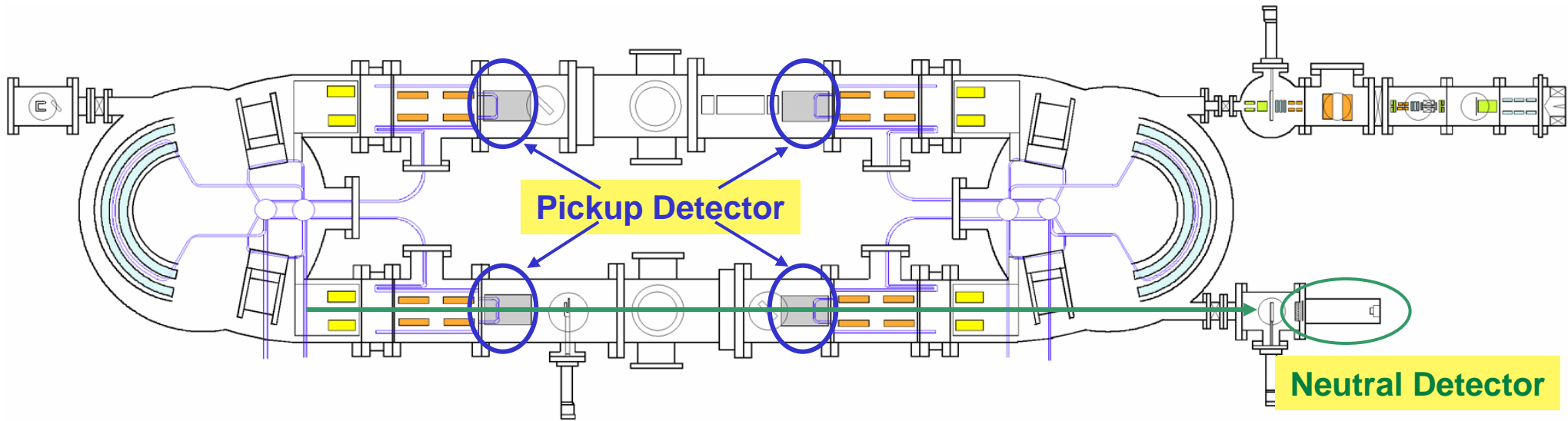


# Beam Storage Test

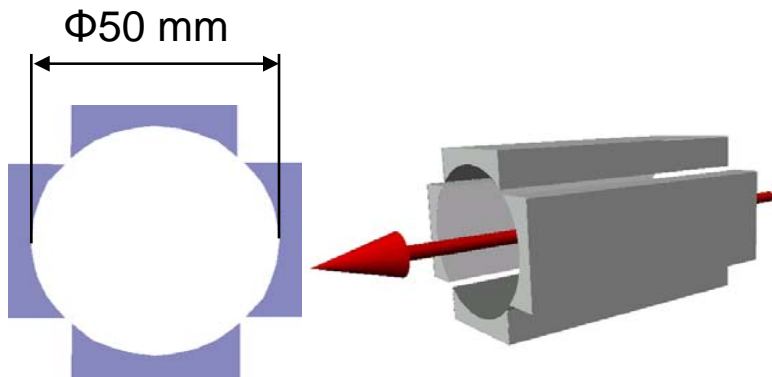
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- Rare gas atomic ions from Duoplasmatron: He<sup>+</sup>, Ne<sup>+</sup>, Ar<sup>+</sup>, Kr<sup>+</sup>, Xe<sup>+</sup>
- Neutral Product Detector
  - useful both for DC and BUNCHED beam
- Pickup Detector
  - useful for BUNCHED beam  
(useless for DC beam )

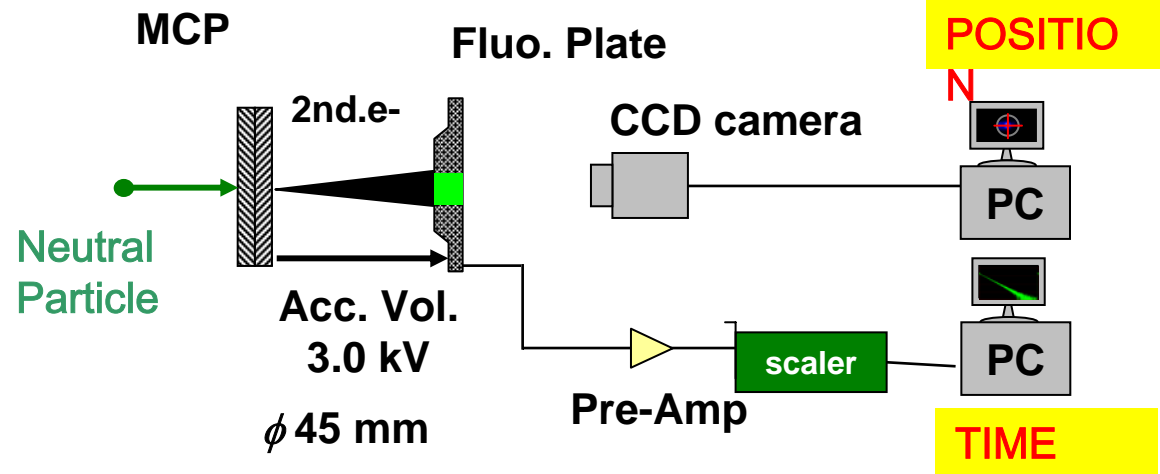
# Monitor for Beam Diagnosis



## Pickup Detector x 4

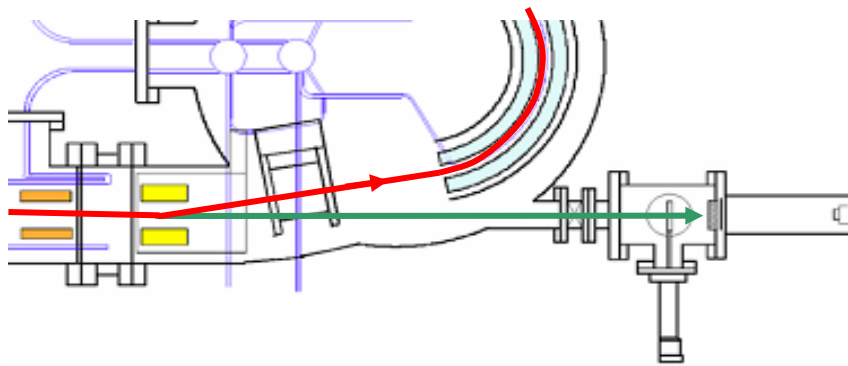


## Neutral Detector x 1

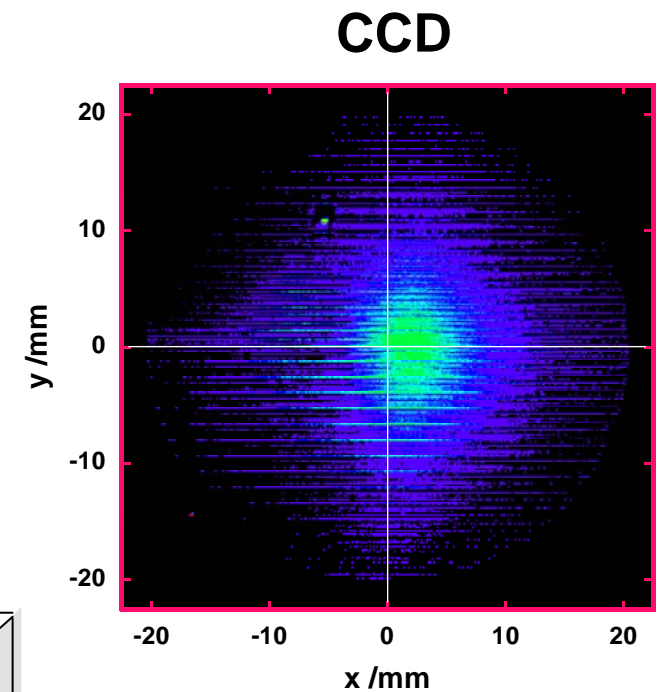
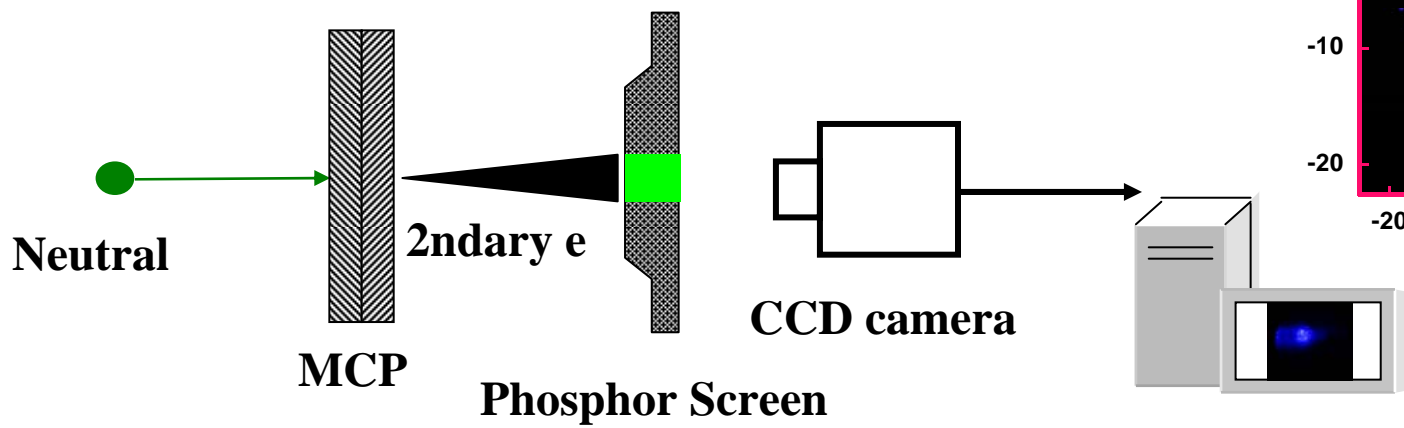


# Neutral Detector [2D-position]

micro-channel Plate (MCP)  
( 2stage, 45mm $\phi$ )  
+ Phosphor Screen + CCD camera



Position-Information

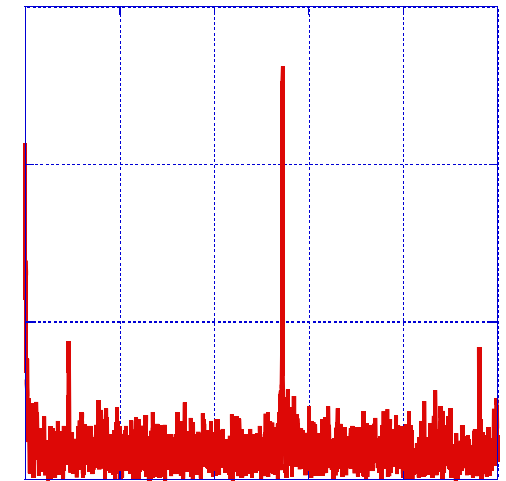
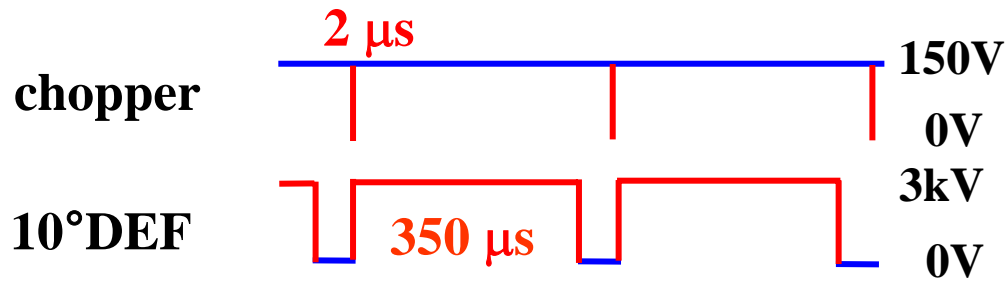


# Neutral Detector [time]

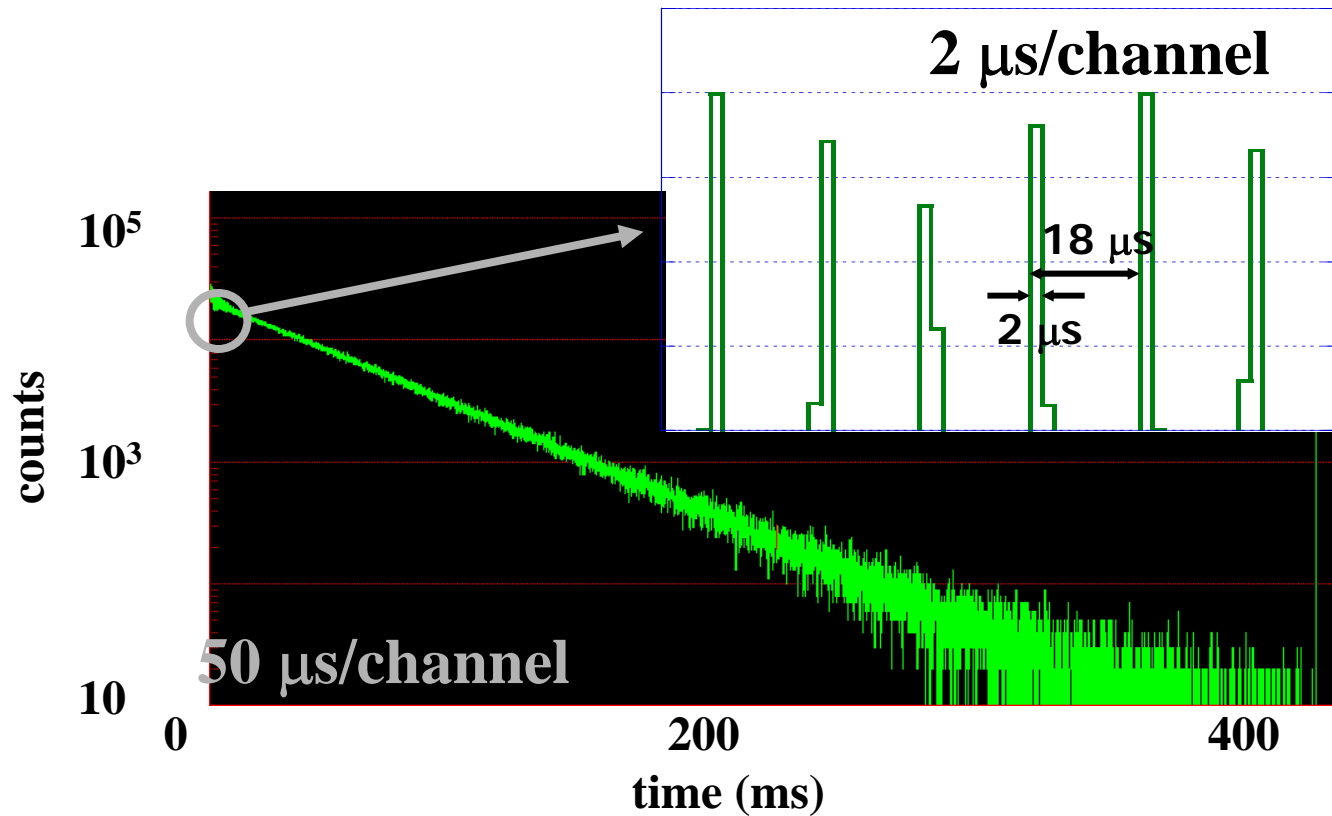
FEB. 26/2004

20keV Ne<sup>+</sup> 10<sup>6</sup> ions/pulse, 6.5×10<sup>-6</sup> Pa

FIRST STORAGE



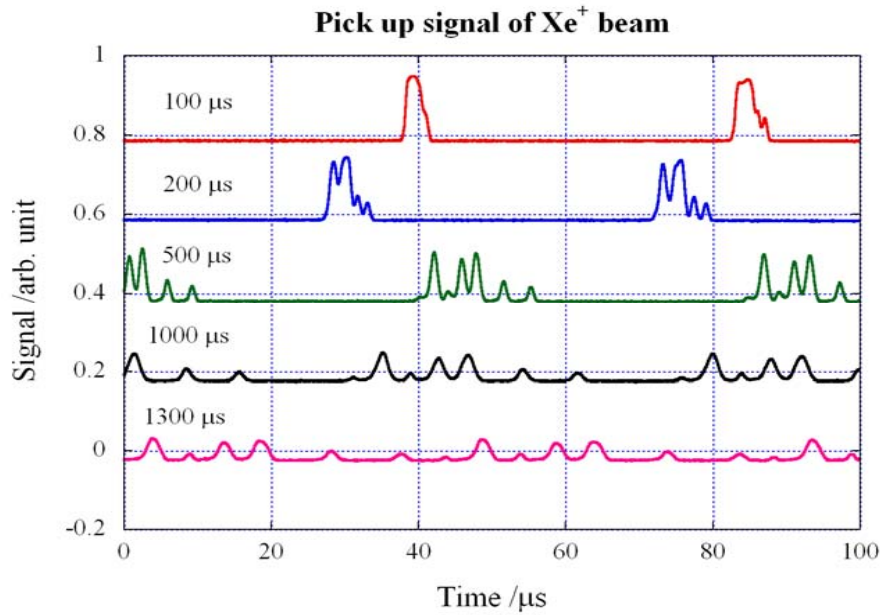
FT



$\sigma \sim 10^{-15} \text{ cm}^2$   
 $\tau \sim 100 \text{ ms}$

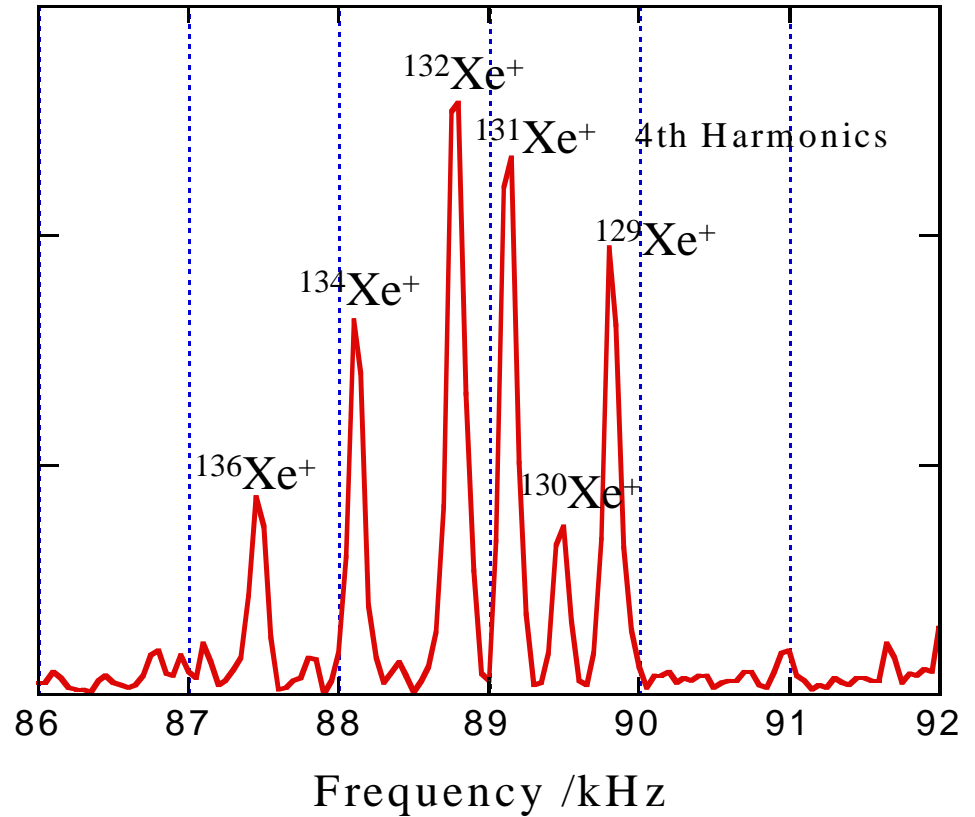
# FT mass spectroscopy of Xe<sup>+</sup>

JULY / 2004



## Separation of isotopes

$\Delta E/E=565$



<sup>124</sup>Xe: 0.1%

<sup>126</sup>Xe: 0.09%

<sup>128</sup>Xe: 1.91%

<sup>129</sup>Xe: 26.4%, 89.6 kHz

<sup>130</sup>Xe: 4.1%

<sup>131</sup>Xe: 21.2%, 88.8 kHz

<sup>132</sup>Xe: 26.9%, 88.4 kHz

<sup>134</sup>Xe: 10.4%, 21.9 kHz

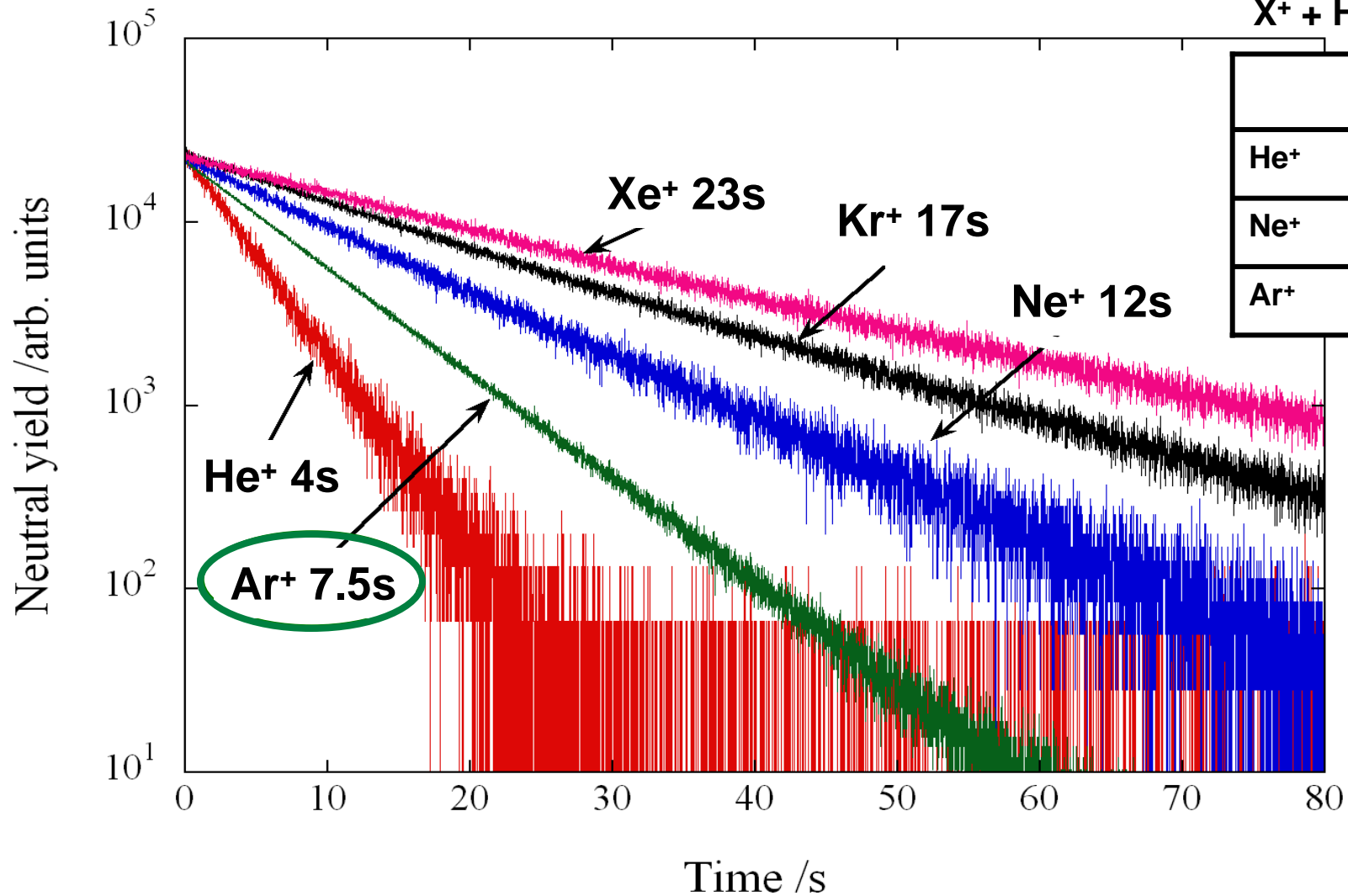
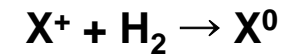
<sup>136</sup>Xe: 8.9%



# Storage Time of Rare Gas Ions

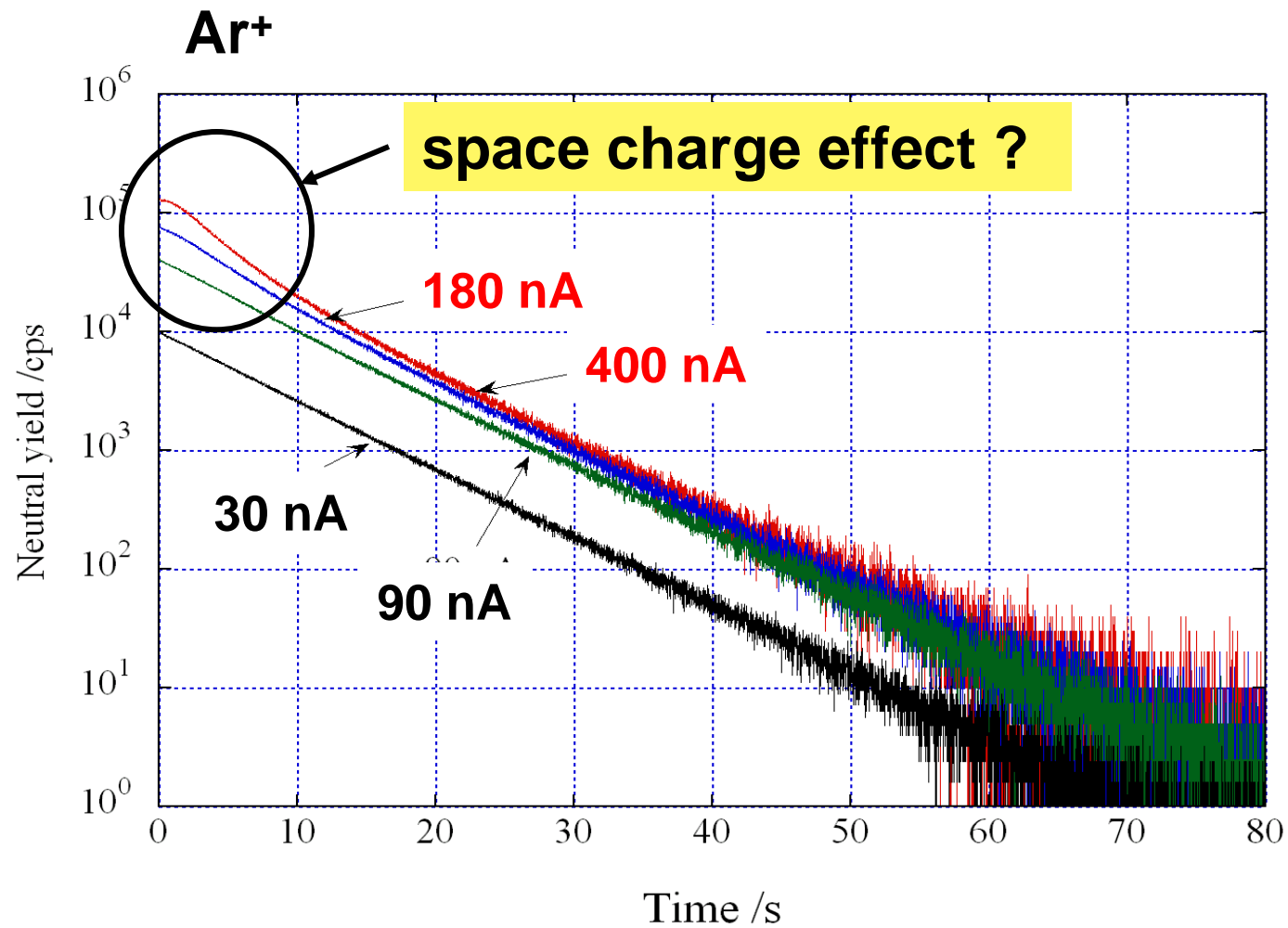
$\sim 5.0 \times 10^{-9}$  Pa, observation of storage =  **$\sim$  a few min.**

electron capture



	$\sigma_{\text{cap}} / \text{cm}^2$
He <sup>+</sup>	$2.5 \times 10^{-16}$
Ne <sup>+</sup>	$6.0 \times 10^{-17}$
Ar <sup>+</sup>	$8.0 \times 10^{-16}$

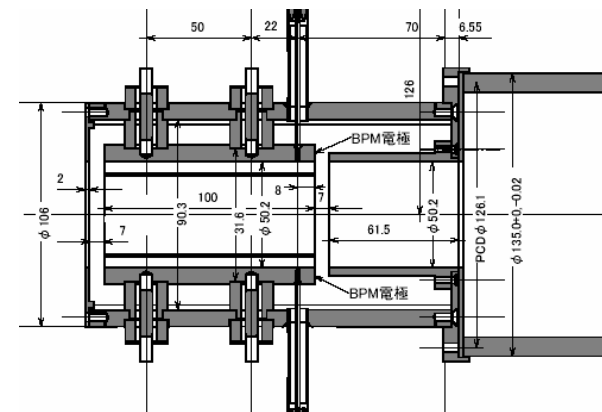
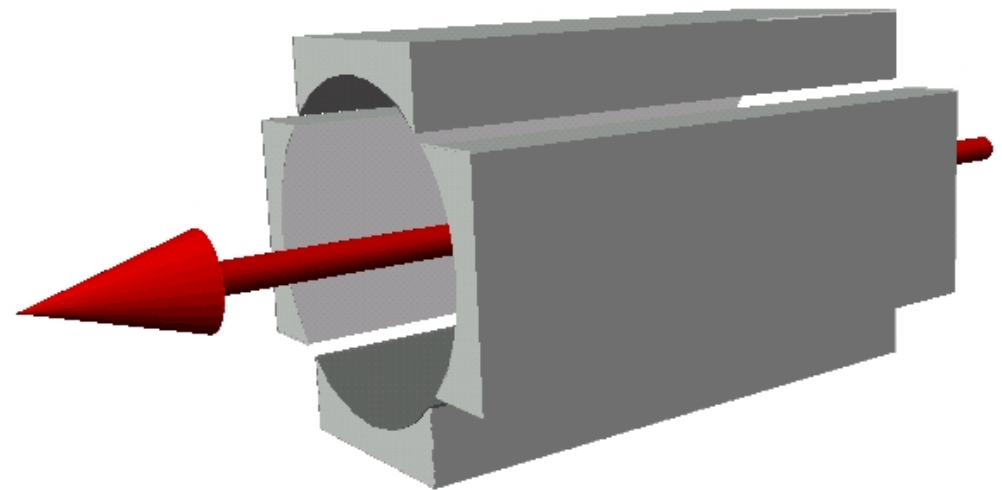
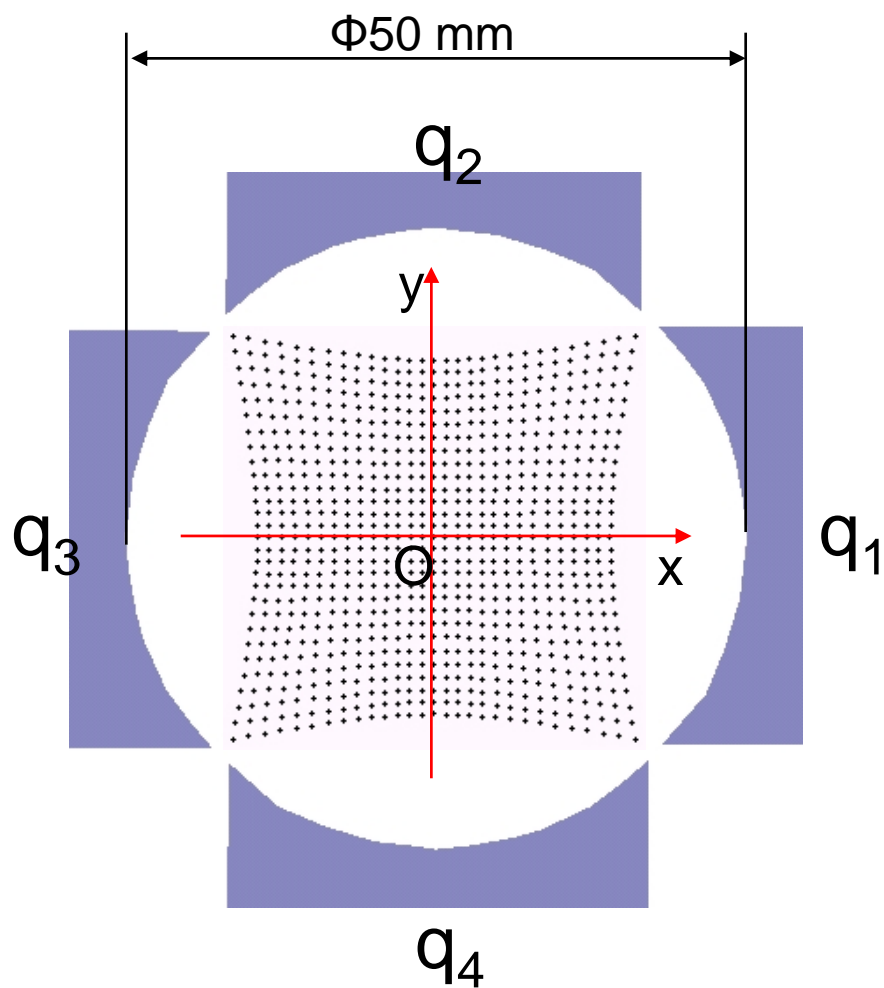
# Beam Intensity Dependence of Storage Time



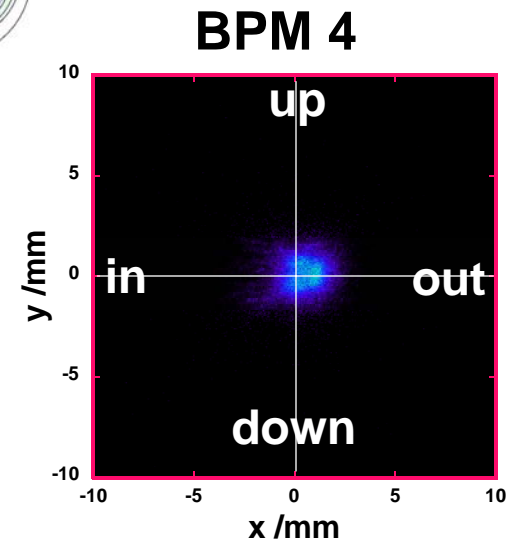
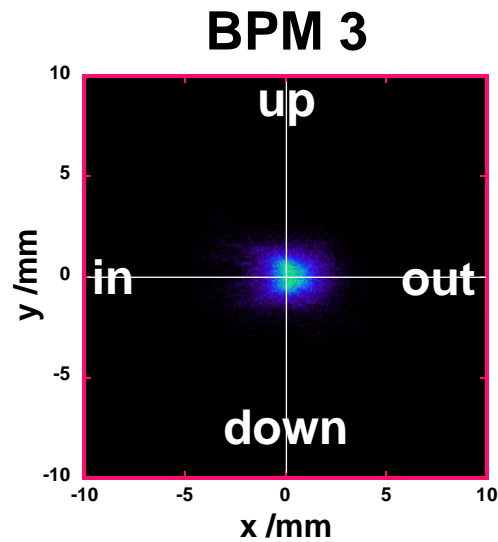
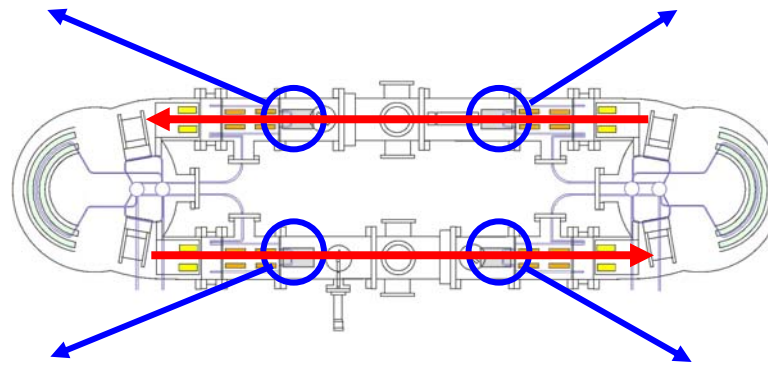
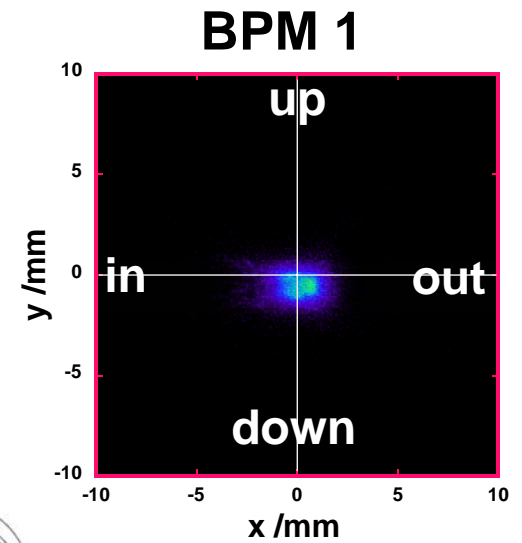
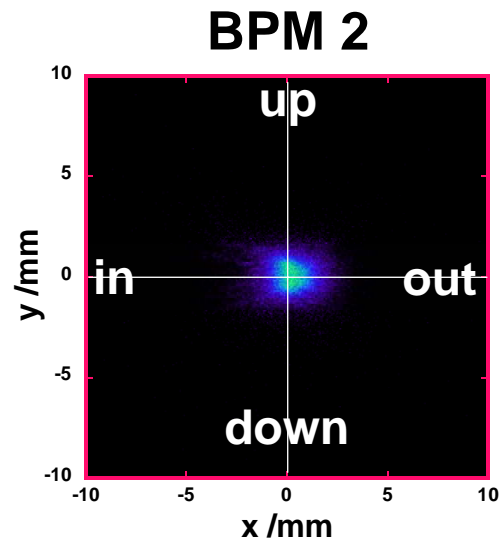
# Beam Position Monitor (BPM) TYPE II

SEP / 2004

4 segmented electrodes: beam position



# Beam Center Observed by 2D-Position Monitor

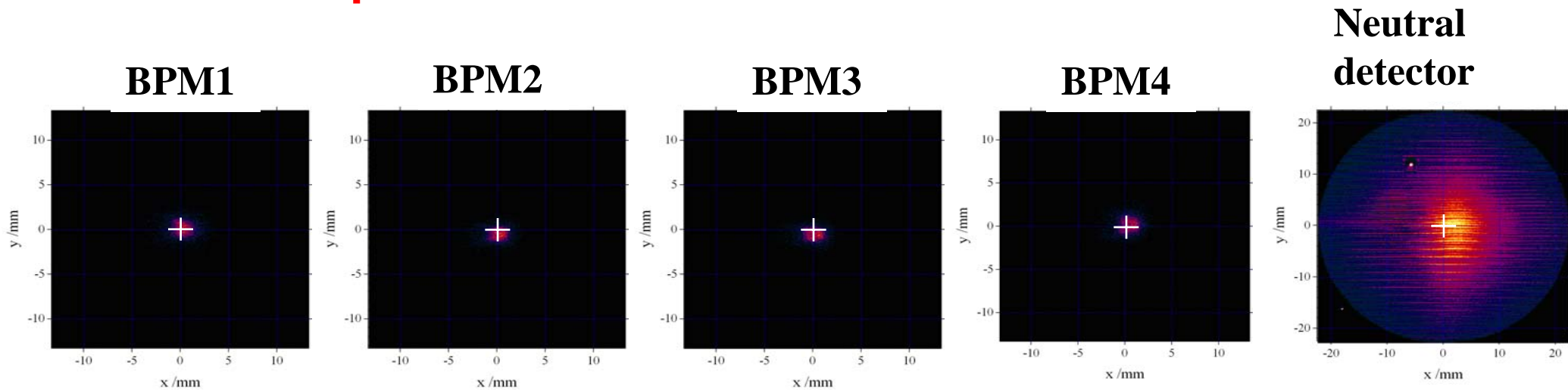




# Beam trajectory under room temp. and LN<sub>2</sub> 1/2

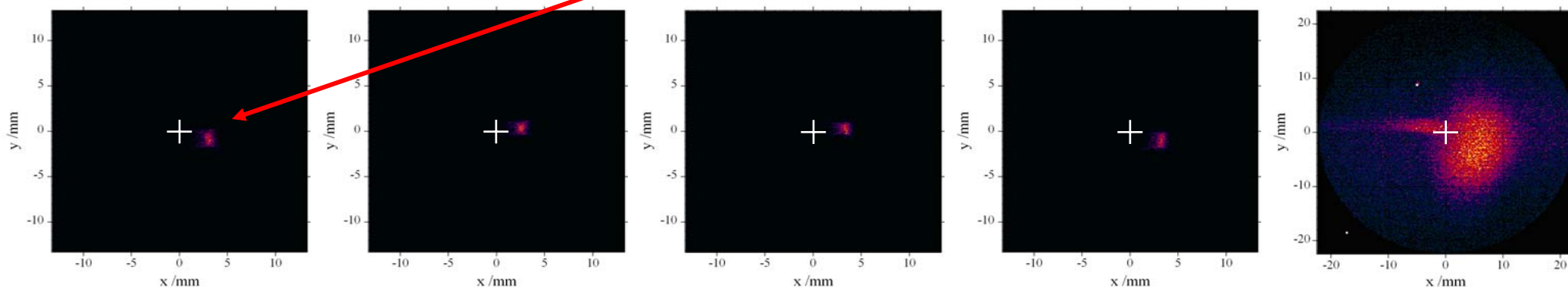
Influence of the thermal shrinking: yes but not much

Room temperature



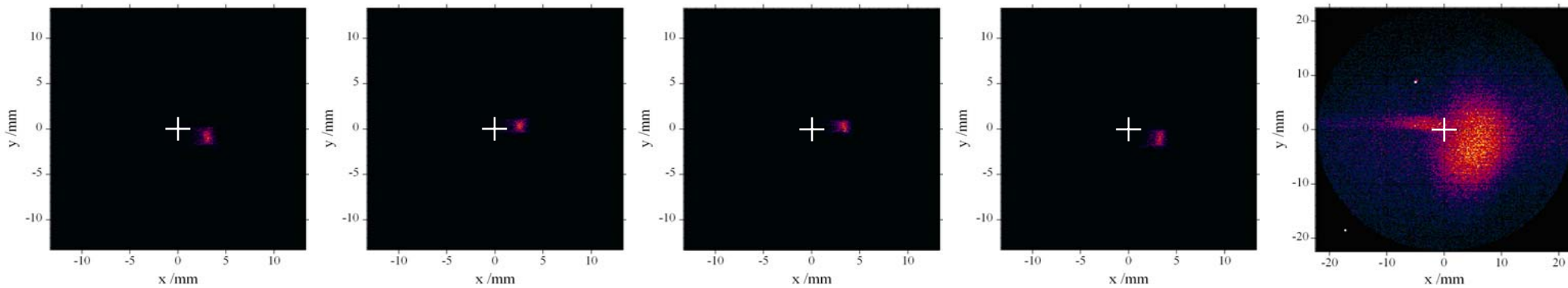
LN<sub>2</sub> temperature

shrinking of electrodes: max. ~ 1mm deviation from the center



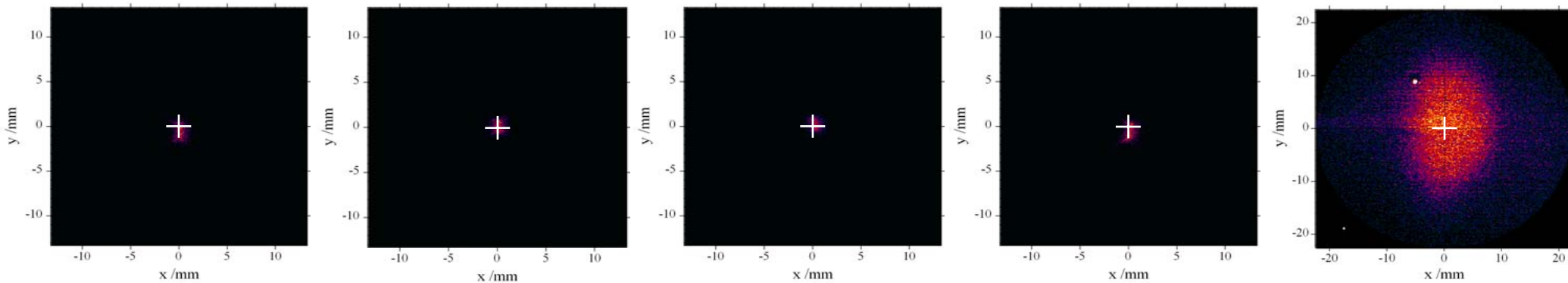
# Beam trajectory under room temp. and LN<sub>2</sub> 2/2

LN<sub>2</sub> temperature



After adjusting the parameters

(less than 1%)

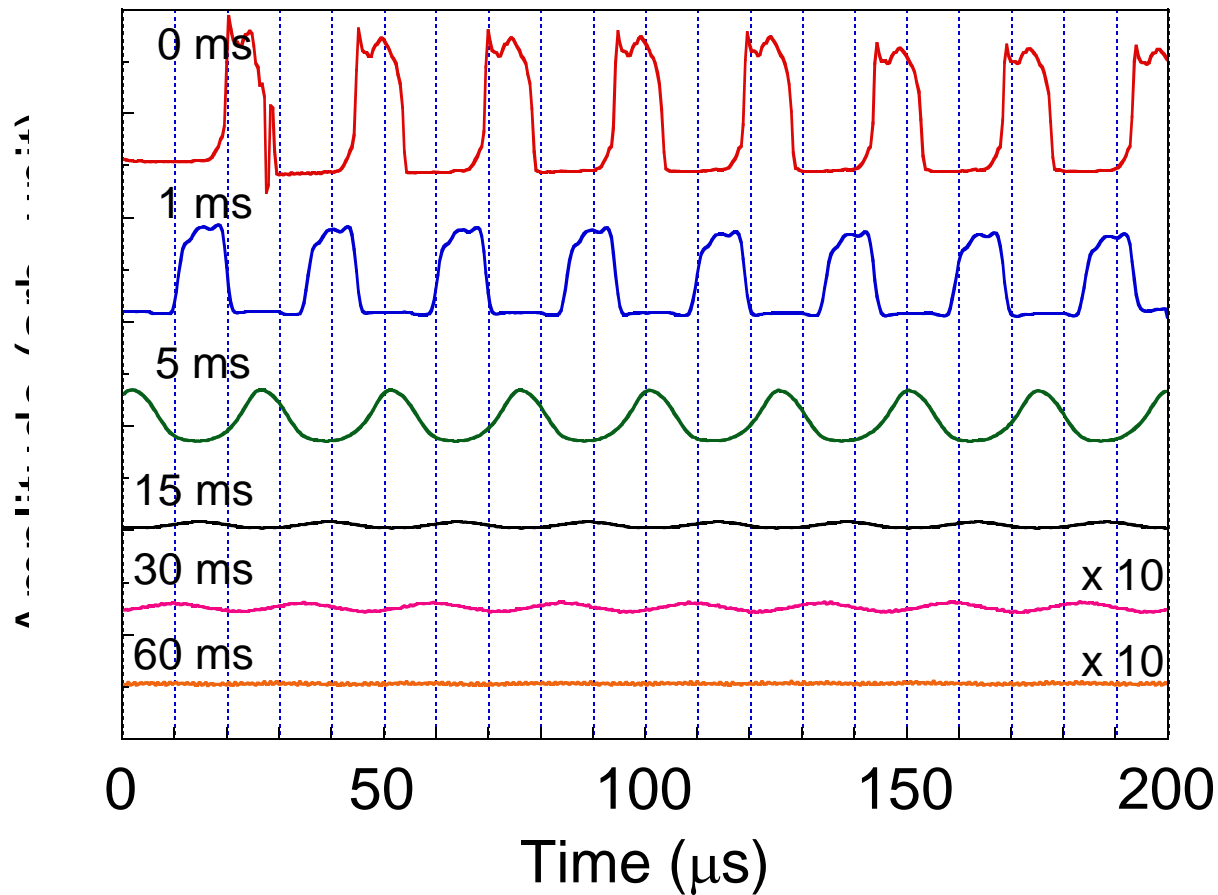


# De-Bunching and Bunching

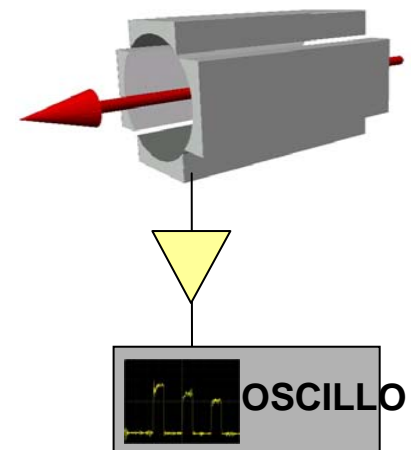
DEC / 2004

- Bunching of DC-beam: Ar<sup>+</sup>
- Selection of a specific ion after simultaneous storage of several kinds of ions : C<sub>60</sub><sup>+</sup> , C<sub>70</sub><sup>+</sup>

# Bunch Structures for Different Time Windows



**Ar<sup>+</sup>**  
**20 keV**  
**width 10  $\mu\text{s}$**   
 **$\sim 10^7$  ions/pulse**  
**Period 25  $\mu\text{s}$**

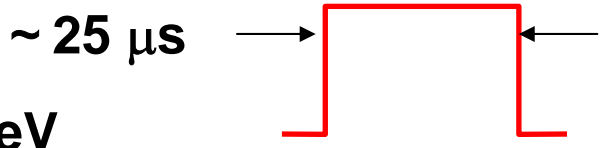
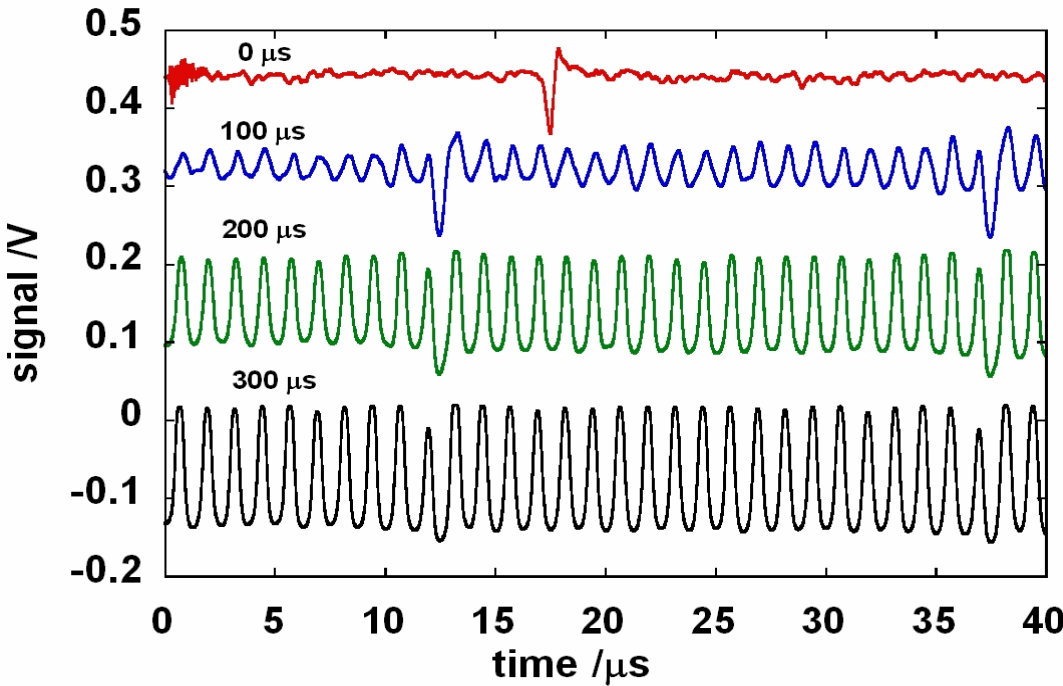


**DC after 60ms**



# Bunching of DC-beam

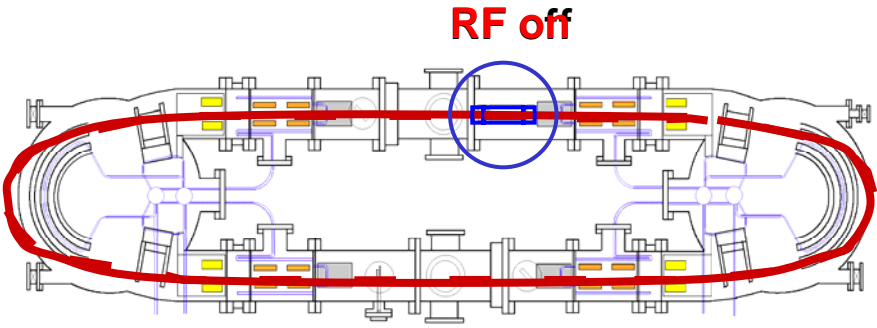
DEC / 2004



Ar<sup>+</sup> 20 keV  
Pulse Width  $\sim 25 \text{ ms}$   
equiv. to single circulation

**RF** ( $f = 800 \text{ kHz}$ ,  $V_{pp} = 20 \text{ V}$ )  
↓  
20 bunches  
300 μs after RF-on

Good for merging experiments with a pulsed LASER due to Better S/N ratio in coincidence



# OPO LASER

AUG / 2005

Laser spectroscopy with OPO tunable LASER



# PHYSICS and CHEMISTRY under way

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- Carbon Cluster Ion

**Positive  $C_{60}^+$ ,  $C_{70}^+$**

selection of specific ions for simultaneous storage of several species of ions

**Negative  $C_{60}^-$ ,  $C_{70}^-$**

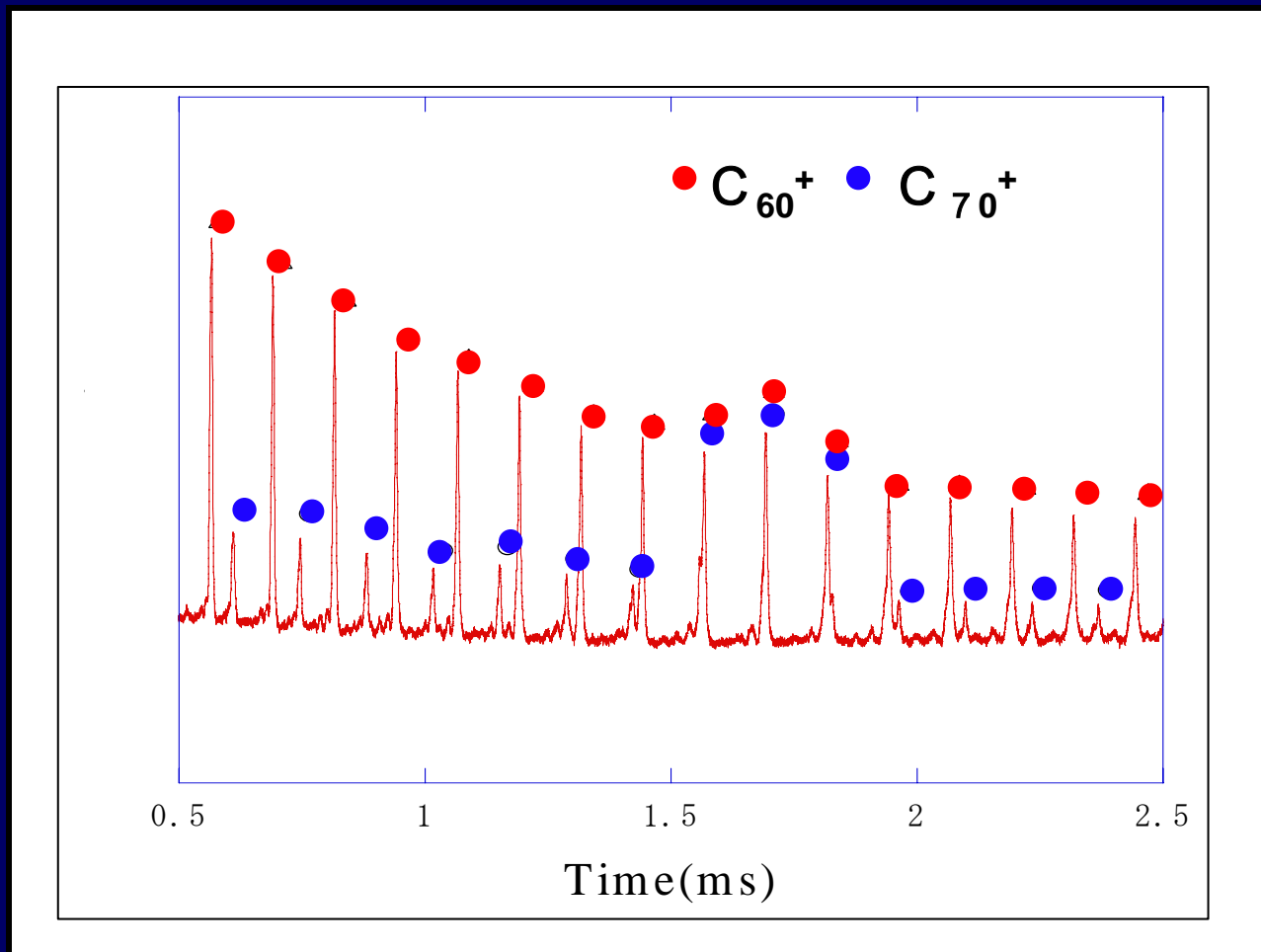
- Large Molecular Ion

**Negative Porphyrin  $H_2TPP^-$**

**LASER spectroscopy**

# Fullerene Cations $C_{60}^+$ , $C_{70}^+$ Simultaneous Storage

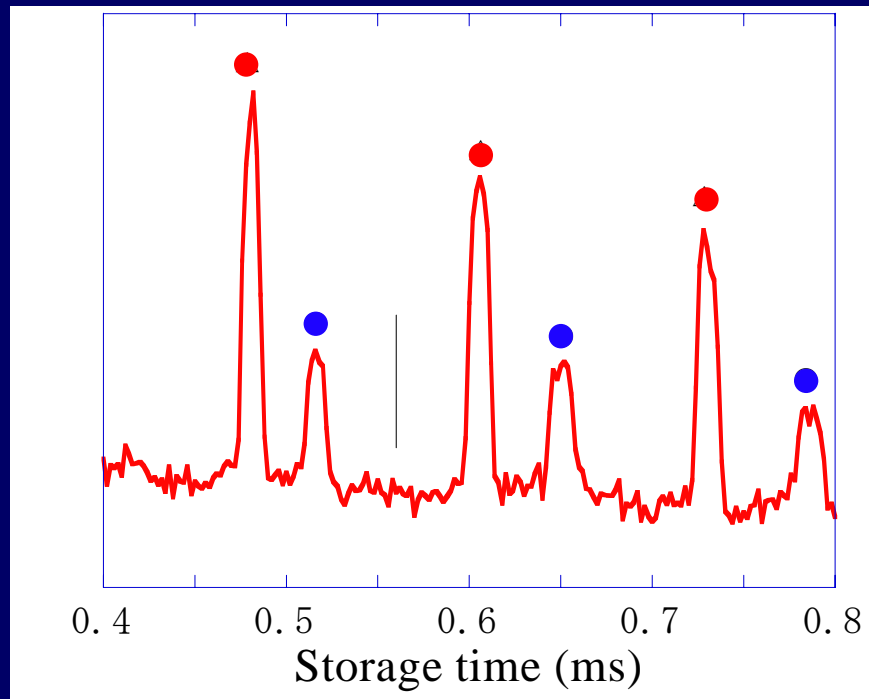
MAR / 2005



**10nA**  
**( $10^5$ ions/pulse)**

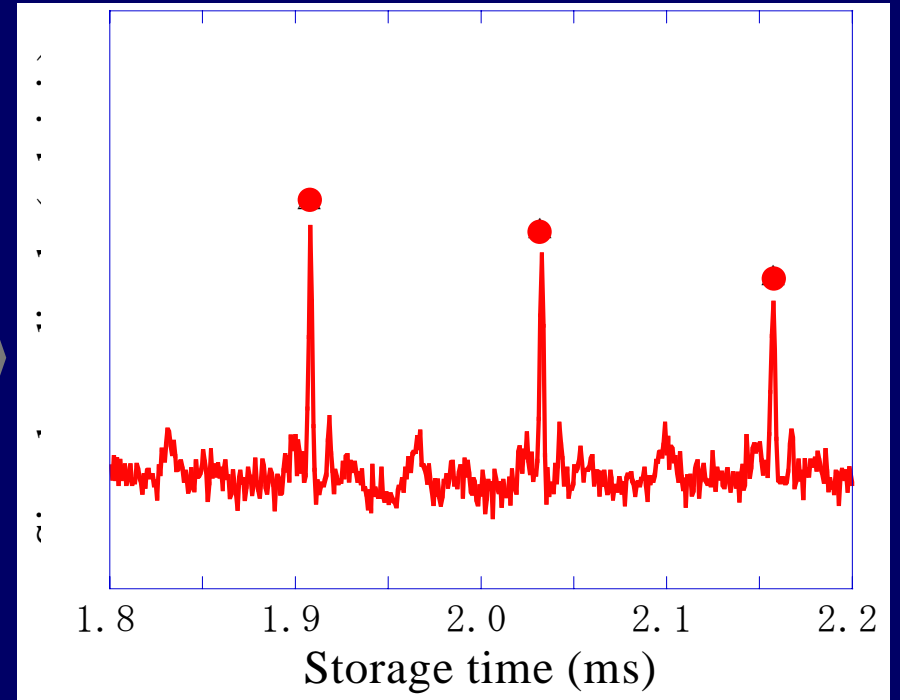
	Mass(amu)	$T$ ( $\mu$ s/period)
$Ar^+$	40	29
$C_{60}^+$	720	122
$C_{70}^+$	840	132

# Bunching of Specific Ions



( ● :  $C_{60}^+$ , ● :  $C_{70}^+$  )

RF on

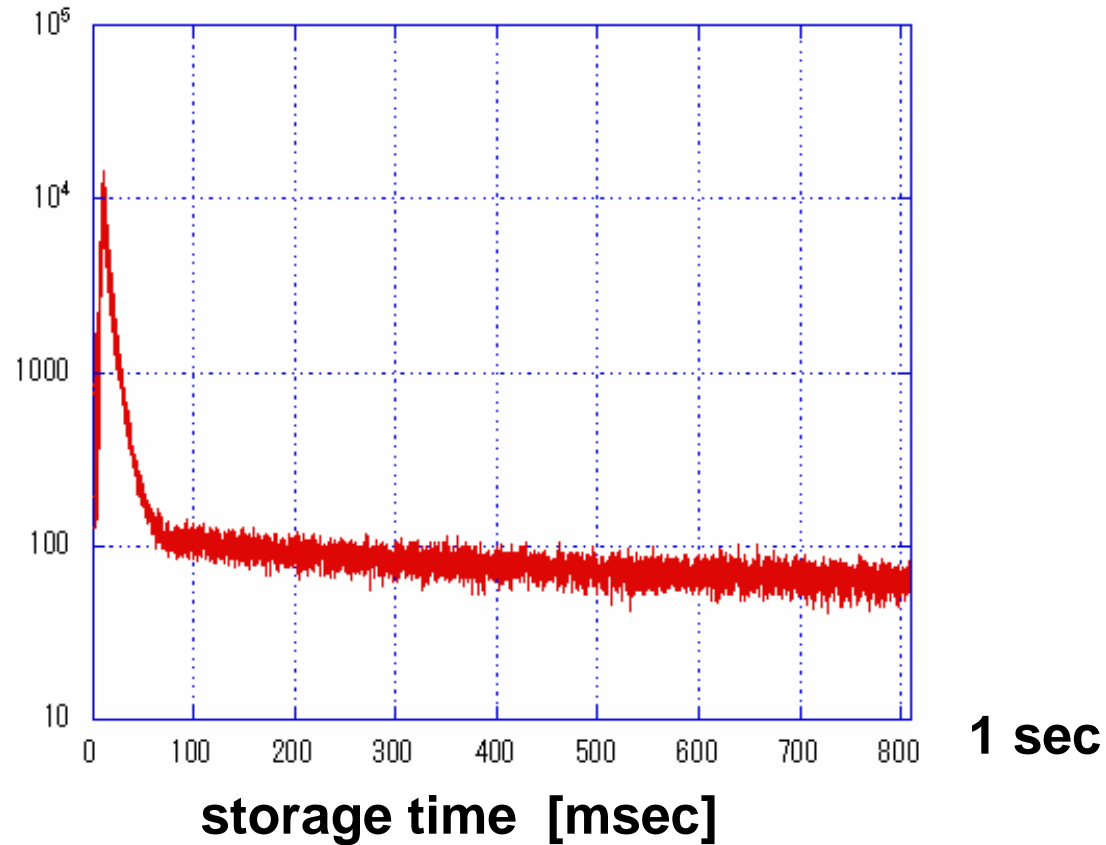




# Ion storage profile of fullerene anions $C_{60}^-$

neutral detector:

long range profile

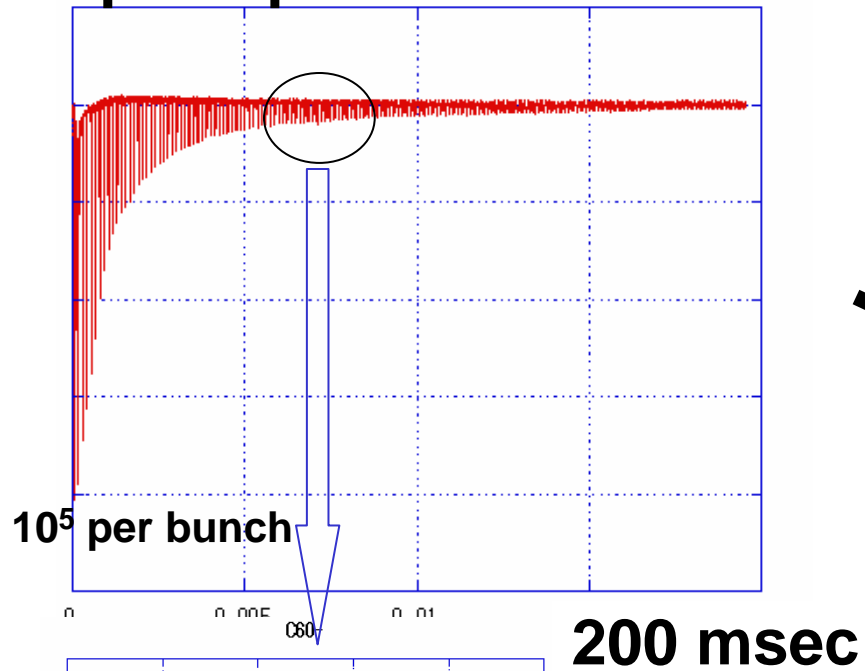


**short lifetime : autodetachment of electron**

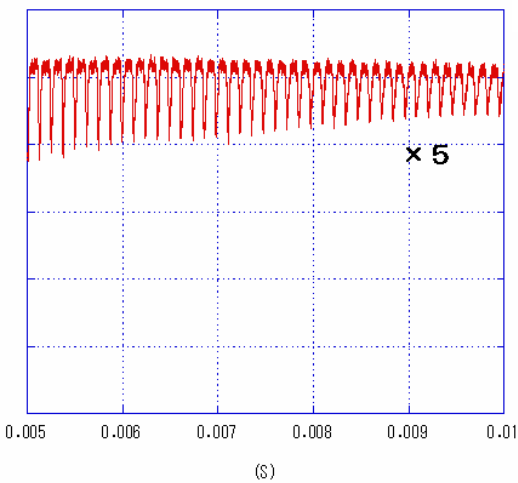
**long lifetime : collision with residual gas**

# Ion storage profile of fullerene anions $C_{60}^-$

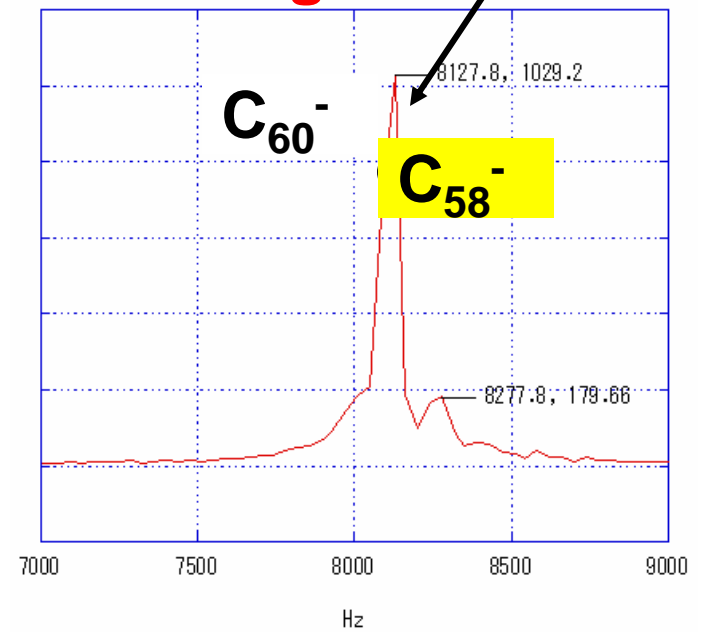
pickup detector:



FT



fragments



# REMPED Spectrum

(Resonance Enhanced Multi Photon Electro Detachment Spectrum)

**Negative ions + tunable LASER: Electron Detachment**



carbon cluster anions

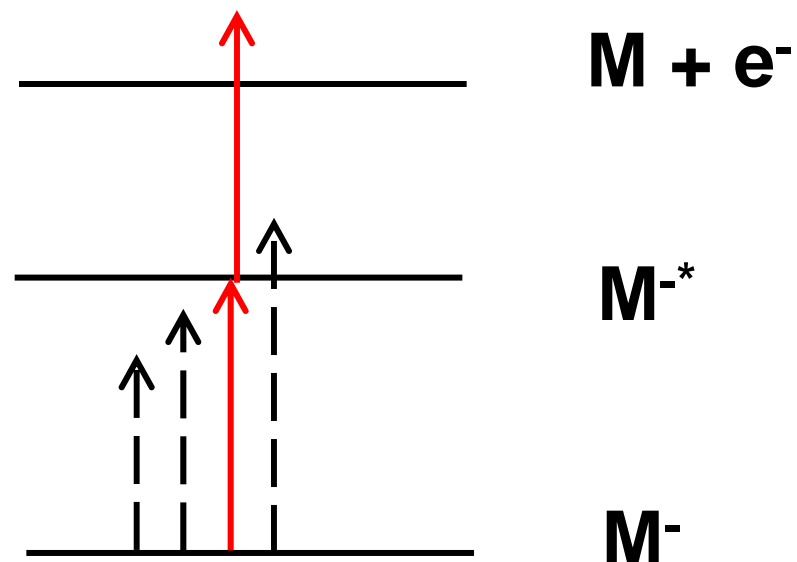
(  $C_5^- \sim C_{21}^-$ ,  $C_{60}^-$ ,  $C_{70}^-$  )



**REMPED Spectra**



**Electronic state of anions and  
structure of cluster**

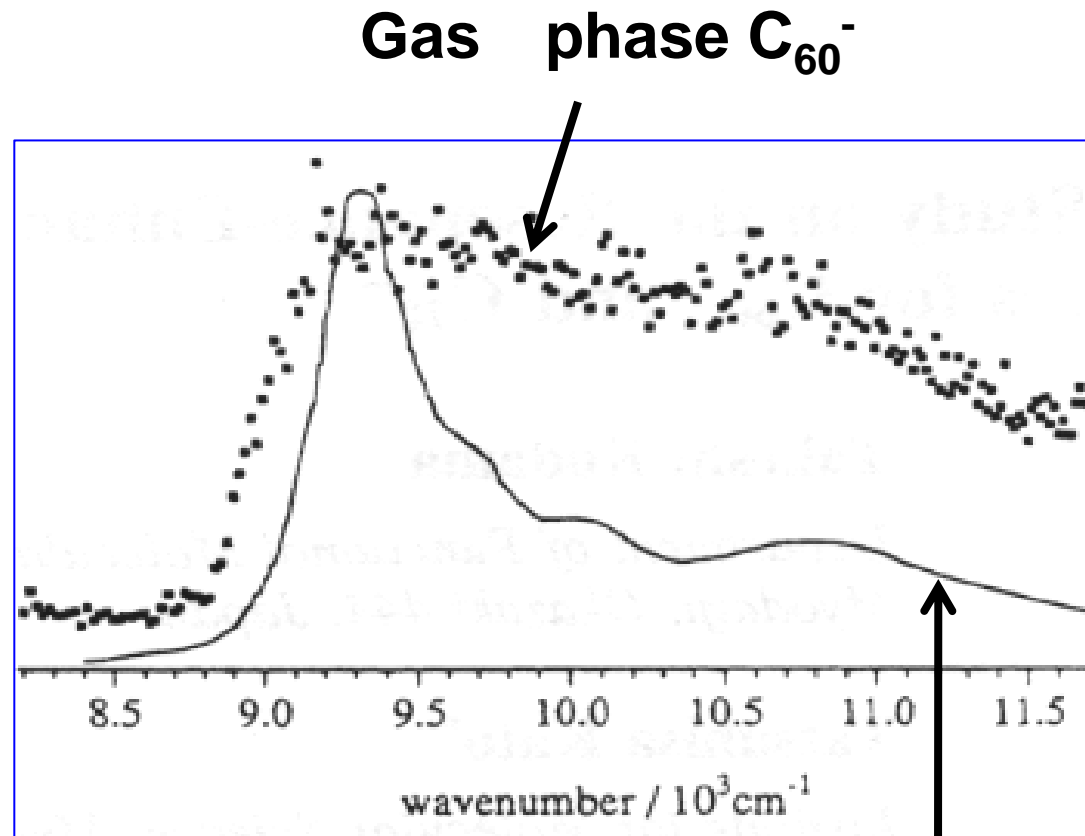


highly-sensitive

selective electron  
detachment

# REMPED Spectrum

(Resonance Enhanced Multi Photon Electro Detachment Spectrum)

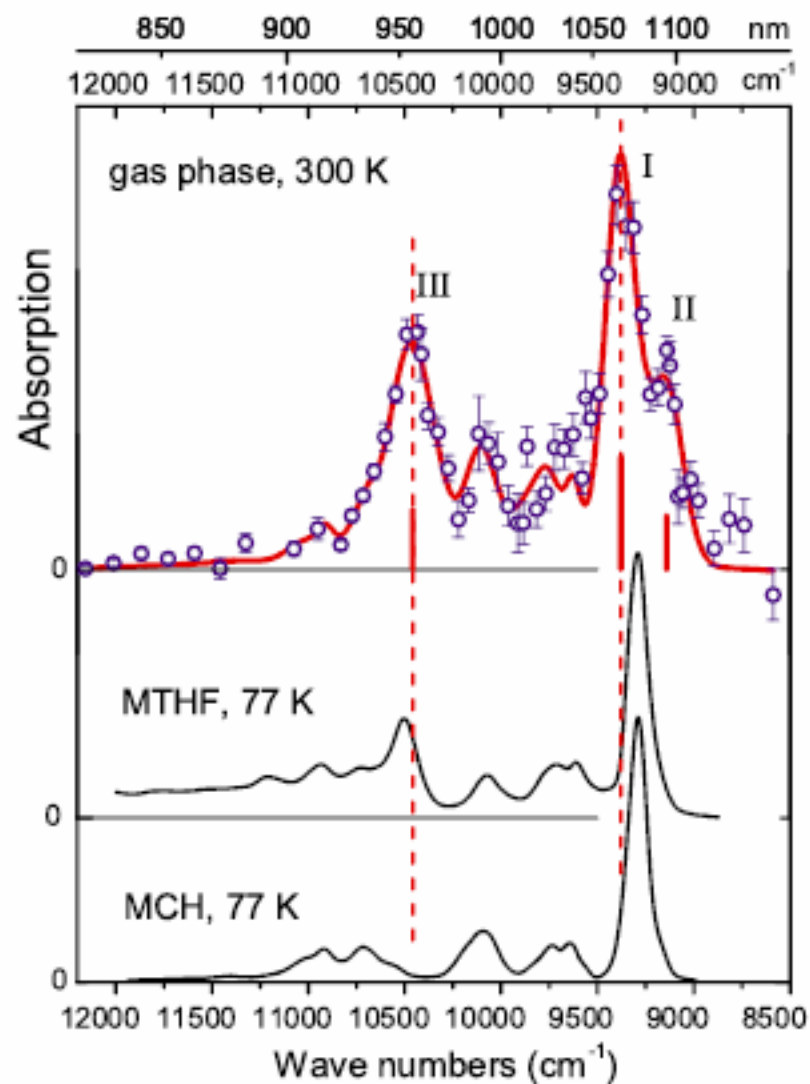


T. Kodama et al, (1994) **TMU Cluster-chemistry Group**

**$C_{60}^-$  Solution**

**Broad spectra due to high temperature of ions**

# REMPED Spectrum



**ELISA**

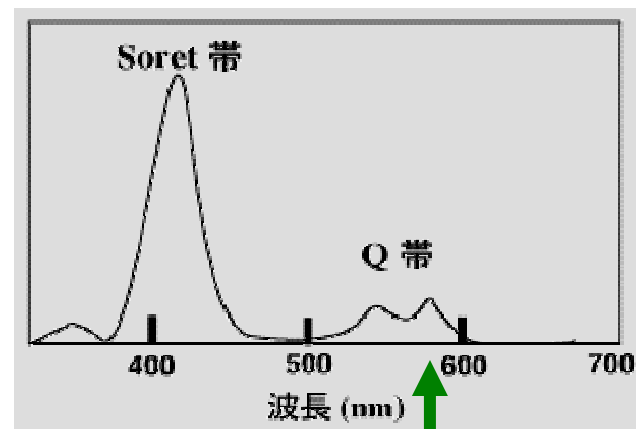
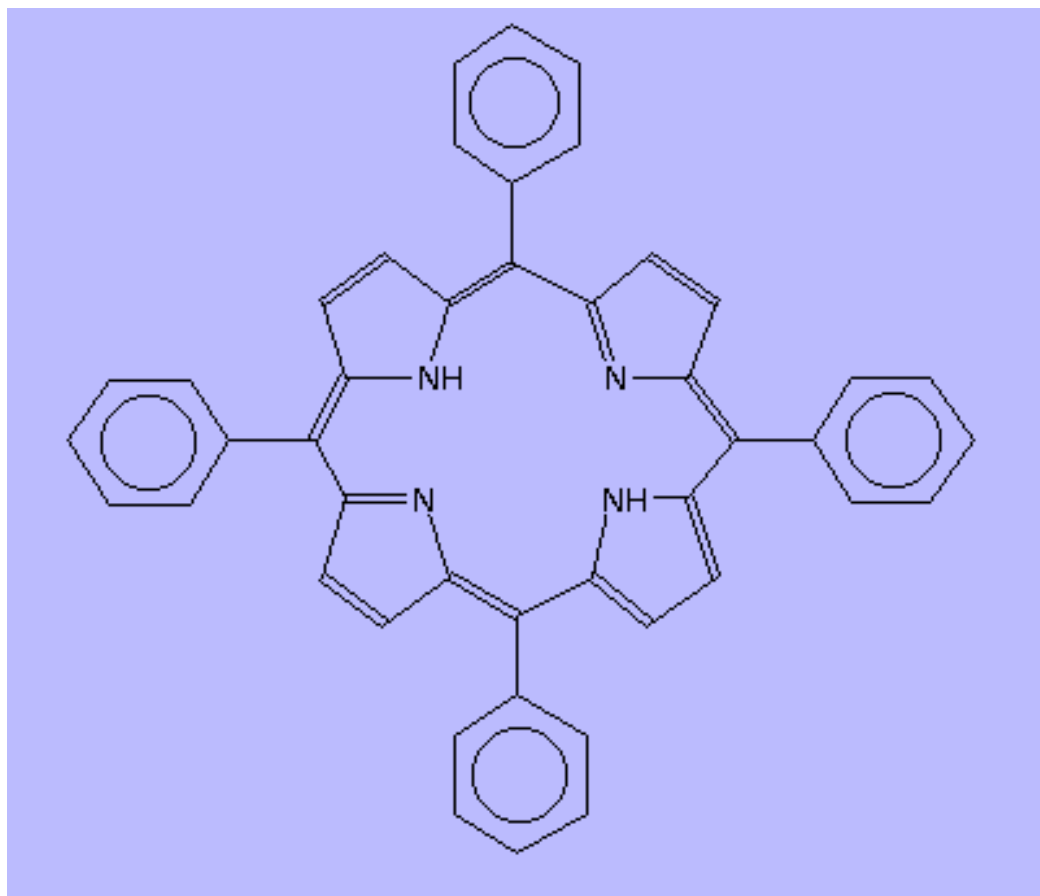
Tomita et al PRL 94, 053002, 2005



# Porphyrin anions $H_2TPP^-$

$H_2TPP$ (5,10,15,20 tetraphenyl-21H,23H porphyrin)

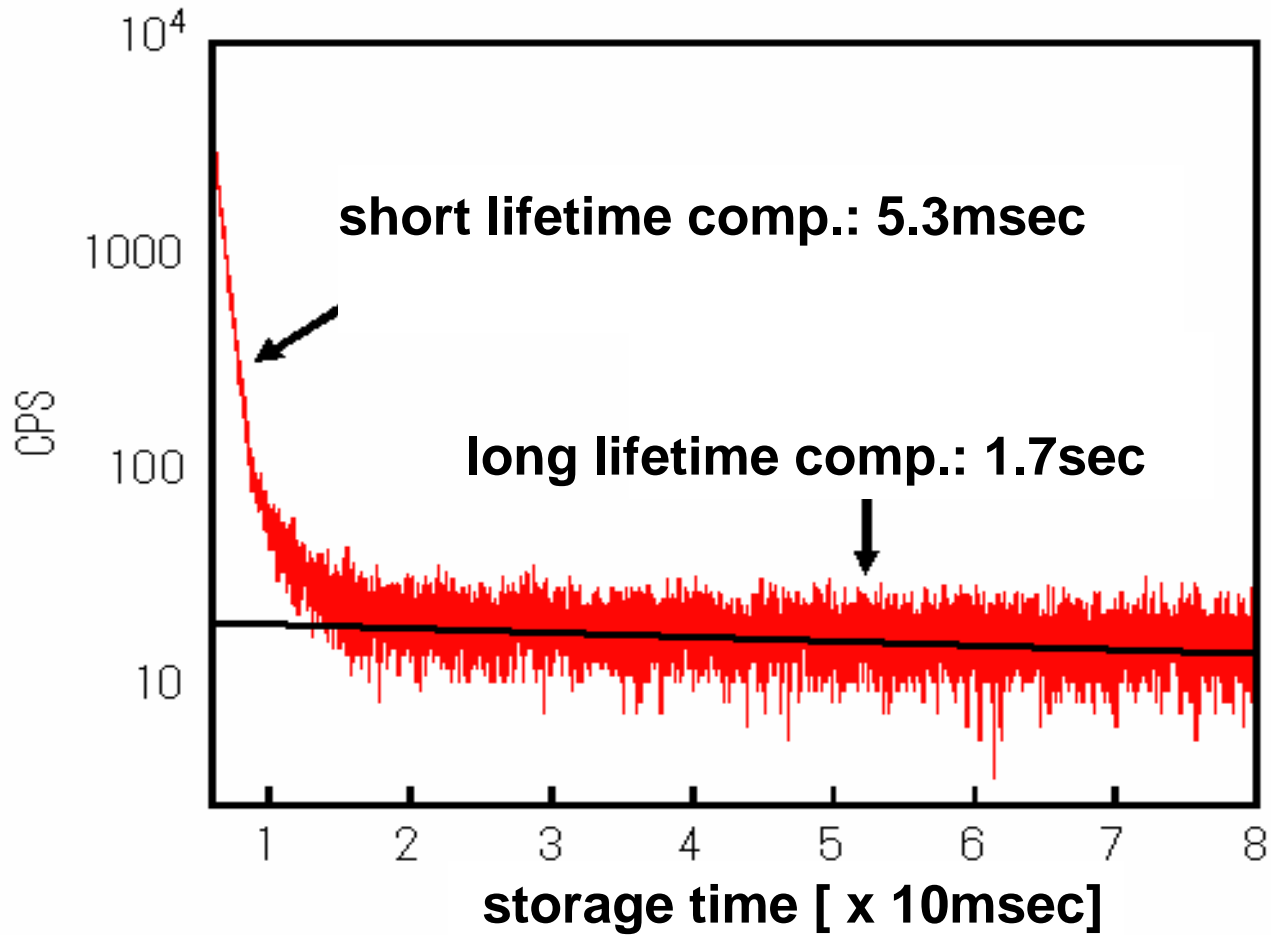
Anion made by MALDI technique (matrix assisted laser desorption )



absorption of  
570 nm photon

# Ion storage profile of Porphyrin anions $\text{H}_2\text{TPP}^-$

Neutral detector



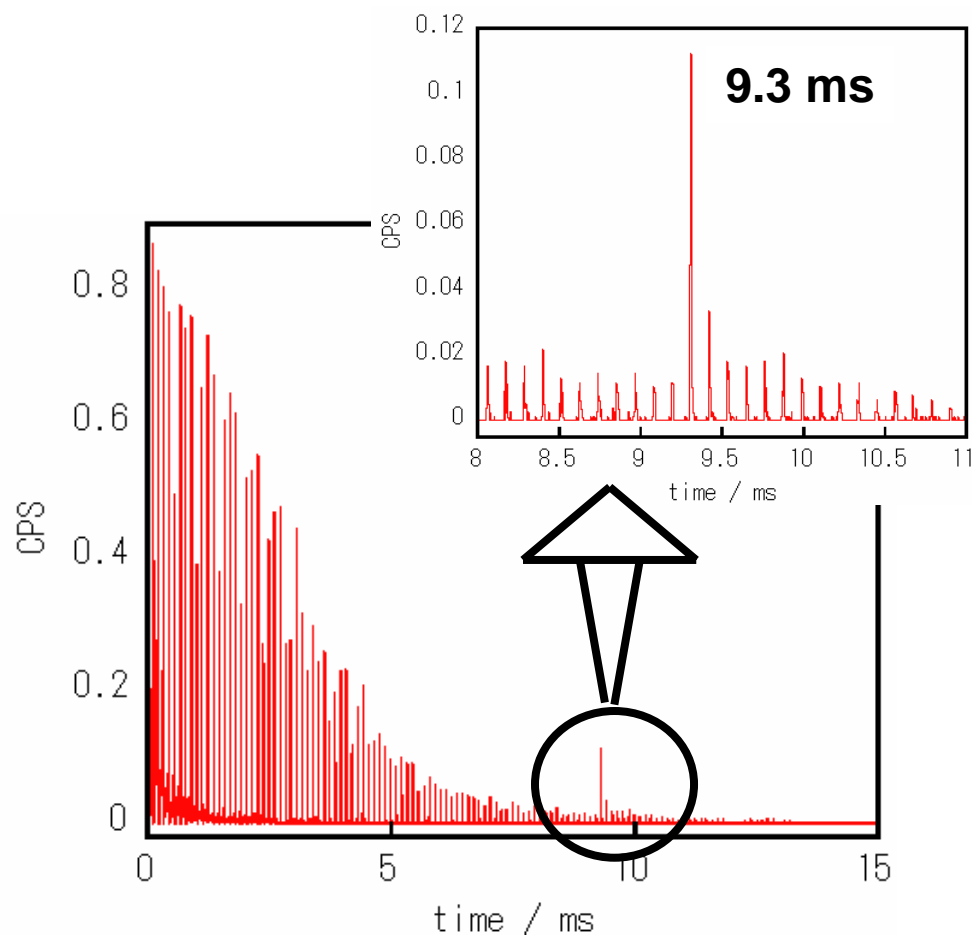
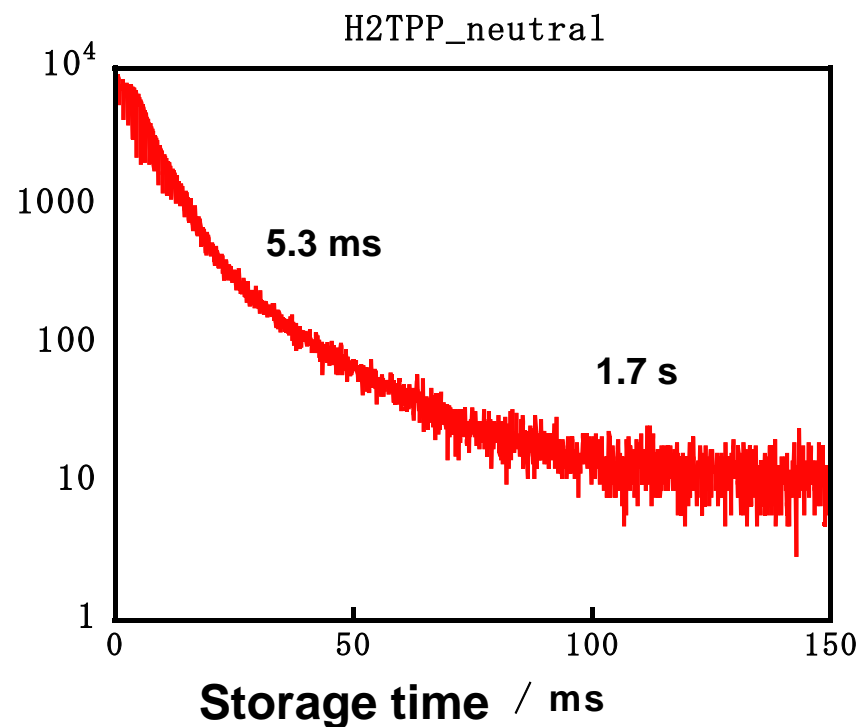
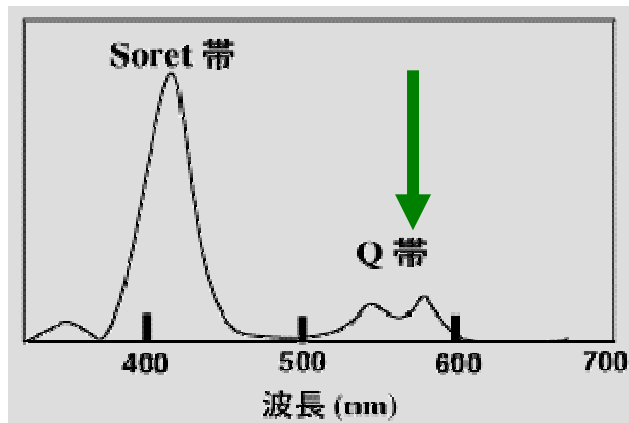
short lifetime : autodetachment of electron

long lifetime : collision with residual gas

# LASER merging exp. of Porphyrin anions $H_2TPP^-$

merging with OPO-tunable LASER

absorption of 570 nm photon



# PHYSICS and CHEMISTRY under way

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- Meta-stable Ion

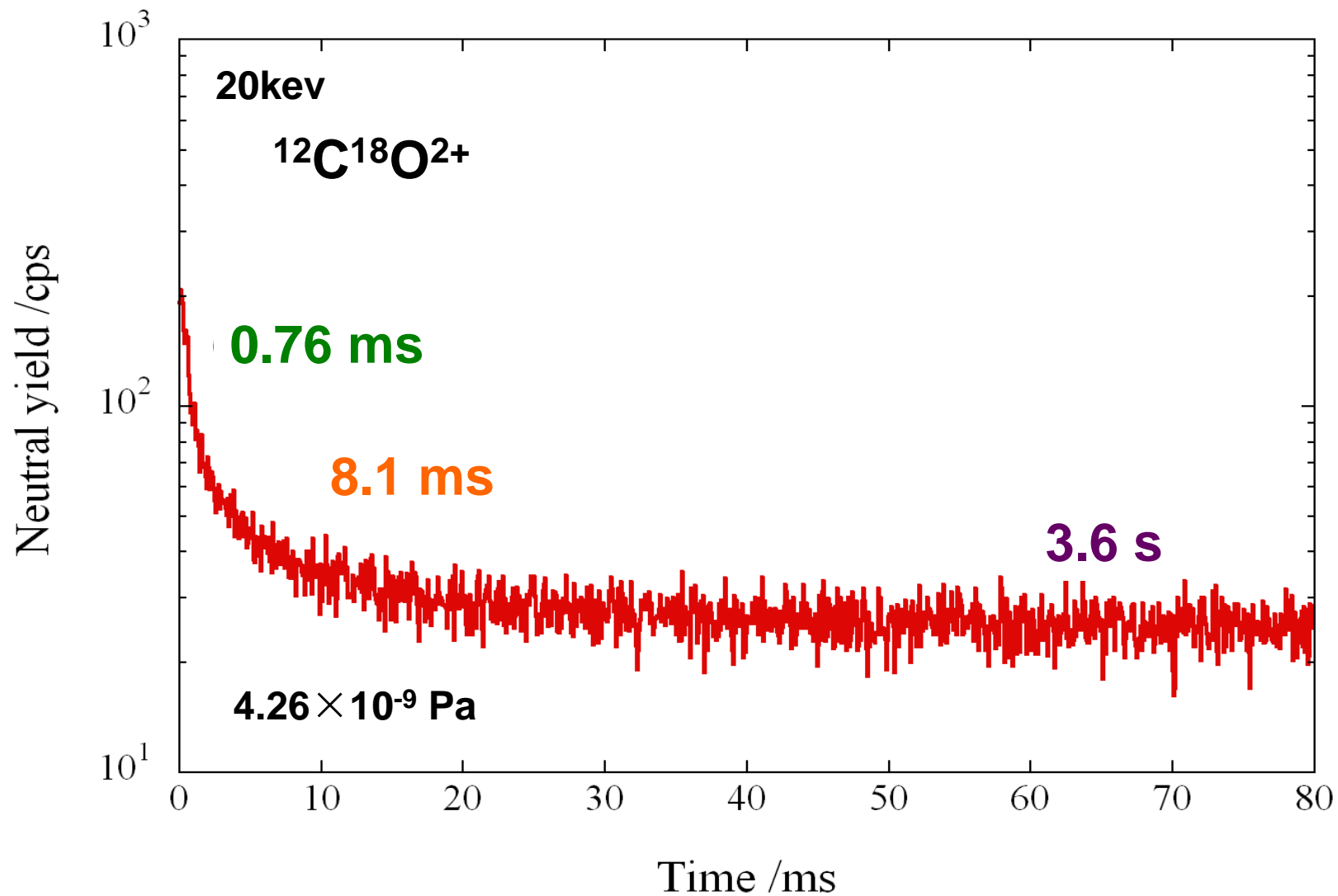
**Doubly charged molecular ion:  $\text{CO}^{2+}$ ,  $\text{CO}_2^{2+}$**

check of proper operation of lifetime measurements  
comparison with previously reported data

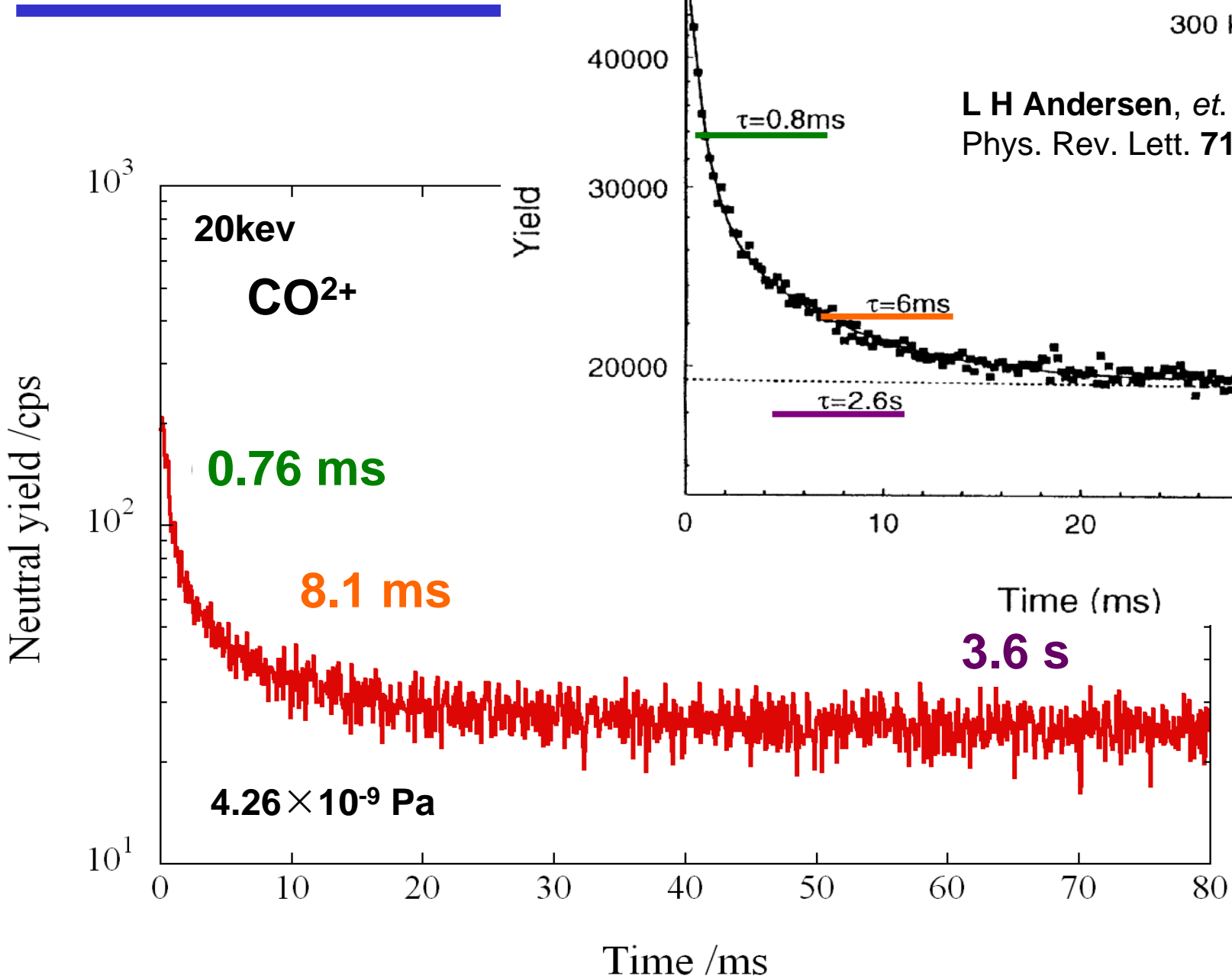
**LASER spectroscopy**

# Storage of Positive Doubly Charged Ions: $\text{CO}^{2+}$

lifetime of metastable state: **msec~sec**

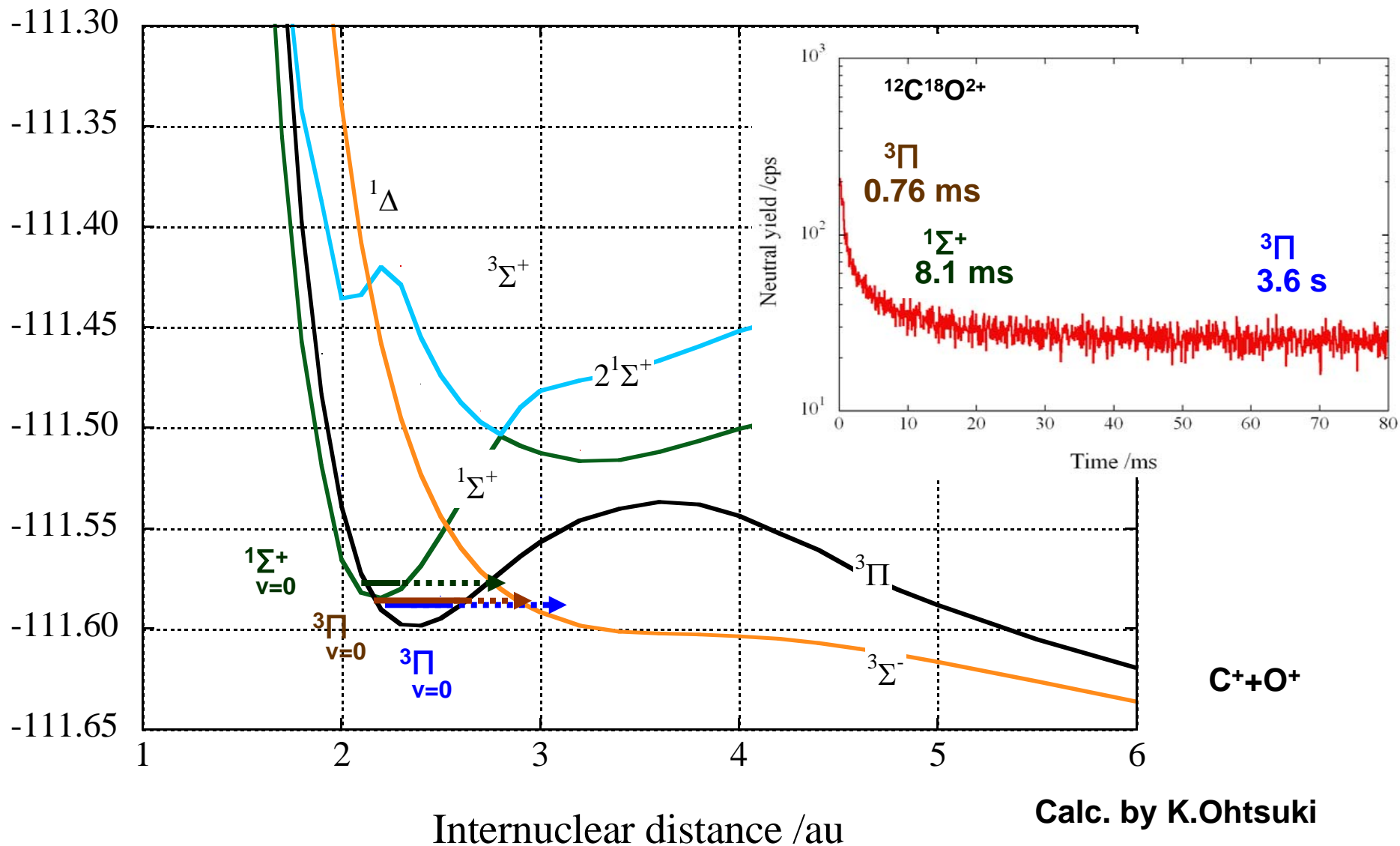






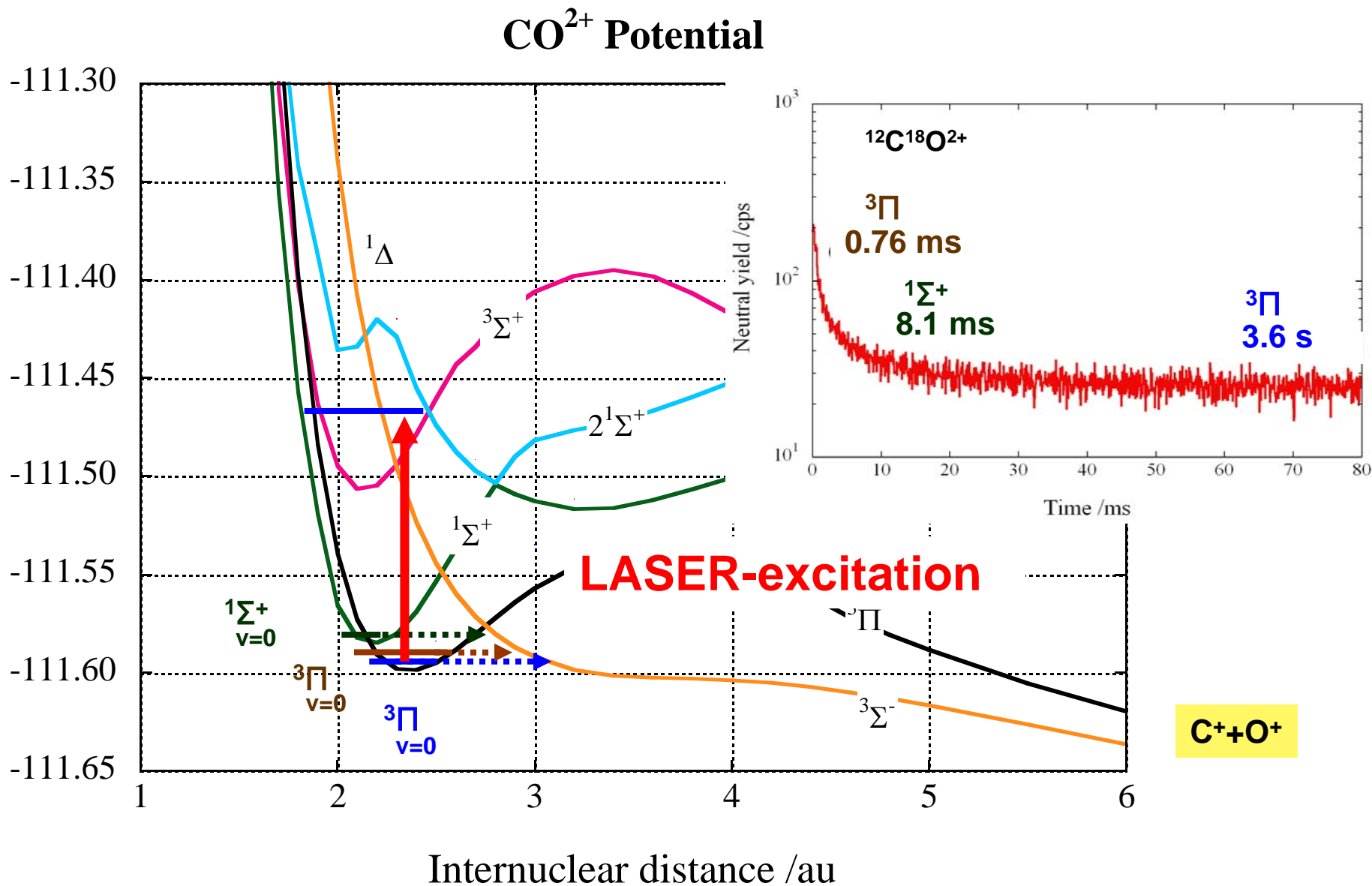
# Storage of Positive Doubly Charged Ions: CO<sup>2+</sup>

Decay rate through tunneling depends on the electronic states.



# LASER spectroscopy of CO<sup>2+</sup>

Now under way / 2005



# Summary

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- Ion storage for more than 1 min.
- Ion storage at **LN<sub>2</sub> temperature**
- **Magnet-free ion injection** system in combination of pulsed-HV and Laser desorption ion source.
- **Simultaneous storage of several kinds of ions**, and selection of a specific ion by bunching technique
- We started **spectroscopy** of cluster/molecular ions by introducing **OPO-LASER**
  - metastable molecular ion
  - cluster/biomolecular ions

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The end

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